Copyright 1945, by the American Society of Naval Engineers

JOURNAL
OF THE
AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. 57 MAY 1945. No. 2

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY
(Under whose supervision this number is published).

Rear Admiral E. W. MILLS, U.S.N.
Mr. W. H. BAILEY.
Rear Admiral A. M. CHARLTON, U.S.N.
Commander H. E. DAVIS, U.S.C.G.
Lieut. Commander E. G. KINTNER, U.S.N.R.
Commander R. T. SUTHERLAND, JR., U.S.N.
Captain P. F. LEE, U.S.N.
Mr. FRED SELLS.
Captain H. C. SEXTON, U.S.N.
Mr. G. B. WARREN.
Rear Admiral F. J. WILLE, U.S.N.

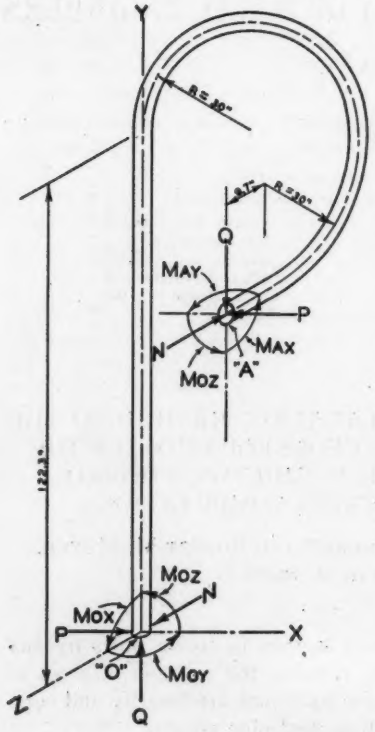
APPLICATION OF A RELAXATION METHOD TO THE SOLUTION OF SIMULTANEOUS EQUATIONS OF THE TYPE THAT OCCUR IN MULTI-ANCHORED PIPE THERMAL STRESS COMPUTATIONS.

BY ALAN OSBOURNE, MEMBER,* AND ROBERT M. MEYER, ASSOCIATE MEMBER.†

The computation of thermal stresses in steam pipes by any one of the standard methods requires the solution of a set of simultaneous equations. These equations are lengthy and complex where they represent a branched pipe system.

The solution of such sets of simultaneous equations with six or more unknowns by substitution, subtraction and elimination or by determinants is exceedingly long and expensive in working time. Several methods have been devised to reduce the labor and amount of computation in solving such equations. The more common of the simplified methods are: the solution by successive

* Principal Marine Engineer, U. S. Maritime Commission.
† Naval Architect, U. S. Maritime Commission.



PIPE PROPERTIES AND WORKING CONDITIONS

1. CARBON STEEL
2. INSIDE DIAMETER 5.761"
3. OUTSIDE DIAMETER 6.625"
4. MODULUS OF ELASTICITY AT 750F IS 25×10^6
5. MOMENT OF INERTIA 40.49
6. TEMPERATURE RANGE 60F TO 750F
7. MOVEMENT FORCED ON PIPE AT THE "O" END.
   "X" DIRECTION -0.085"
   "Y" DIRECTION +0.125"
   "Z" DIRECTION +0.033"

FIGURE I.

(4)

approximation, and the solution of symmetrical equations described in reference (f).

The "relaxation" method is one of successive approximations, and its application to the problem of pipe stress calculations promises to reduce the labor involved. Another feature of this method is that the accuracy of the 20 inch slide rule is sufficient for systems of equations with as many as 12 unknowns. Also a further advantage is that the method is self checking since each operation is a measure of the unbalance of the system of equations.

The method of "Systematic Relaxation of Constraints" was originally devised by R. V. Southwell for the determination of stresses in redundant frameworks. In this type of structure the external forces are either known or assumed and the joint displacements when the framework is at equilibrium are the unknowns. The application to branch pipe flexibility problems is similar to this except that the external reactions are also unknowns, which however can be easily obtained after the displacements and rotations at the junction points are determined.

Convergence by the relaxation method is not assured if the simultaneous equations are not axisymmetric. If all of the pipe flexibility equations of a system refer to a common anchor they will be axisymmetric. In other words "Maxwell relations" are then satisfied.

For the general reader who may wish to apply the relaxation method to equations not axisymmetric occurring from non-elastic problems there is a device for making such simultaneous equations axisymmetric termed "normalization." The process of normalization is described on page 128 of reference (a).

The process of relaxation is a method of solving simultaneous equations with steadily increasing approximation. The degree of accuracy is determined only by the number of relaxations carried out.

The application to the solution of pipe flexibility calculations can best be understood by referring to a simple three plane pipe. (See Figure 1.) The one end of the pipe is assumed fixed at the origin of the coordinate system. The other end which we shall term the "A" end is assumed to be moved from its thermally expanded unstressed condition by the amounts of the displacements ΔX, ΔY & ΔZ. These displacements are known from the projected expansion lengths of the pipe in the three planes, the

coefficient of expansion of the piping material, the temperature range of expansion, and the imposed end movements. A system of moments M_{ax}, M_{ay}, and M_{az} are applied at the "A" end with sufficient intensity to preclude any rotation of this end. The equations describing the pipe under these conditions using Hovgaard-Meyer method of notation are:

1. $\beta_3 P - \beta_2 Q - \beta_1 N = EI\,\Delta X$
2. $-\beta_2 P + \lambda_2 Q - \alpha_2 N = EI\,\Delta Y$
3. $-\beta_1 P - \alpha_2 Q + \alpha_1 N = EI\,\Delta Z$

Where:

β_1, β_2, β_3, λ_2, α_1, α_2, are coefficients determined from the geometry of the pipe by use of the forms published in references (b), (c) or by method of reference (d). The same coefficients determined from the method of reference (e) using it's notation would be I_{xz}, I_{xy}, I_x, I_y, I_z, I_{yz} respectively.
P, Q, N, are the forces necessary to displace the free end of the pipe by ΔX, ΔY, and ΔZ. These forces by reference (e) and its notation would be X, Y, and Z respectively.
E is the modulus of elasticity at the operating temperature.
I is the moment of inertia of the pipe cross sectional area of metal, (not the polar moment of inertia).

We have now a simple system of simultaneous equations symmetrical about the diagonal. In a system of only three unknowns the real merits of the relaxation method will not be so apparent. Its value as a tool increases as the number of unknowns increase. This system was chosen as an example because it is more easily understood than one of greater complexity.

A physical picture of the relaxation process applied to this problem can now be visualized if we imagine the unknown reaction forces P, Q, & N to exist before the pipe is stressed, and that these reaction forces are held from stressing the pipe by three perpendicular constraints. Furthermore our three imaginary constraints must be so designed that they can each be released separately in increments in such a way that the forces P, Q & N may be applied separately in increments to the pipe. Also we must stipulate that the constraints be so designed that the magnitude of each increment of force released can be known. Now suppose the constraint opposing reaction force P is slowly

released to the point where the "A" end of the pipe is displaced by the amount ΔX by the force thus applied to it. We will term this operation one. Now the required displacement ΔX has been applied but the elastic system as described by the equations is unbalanced due to the unsatisfied displacements in the Y & Z directions. The unsatisfied displacements will in effect differ from ΔY & ΔZ by the amount that the displacement ΔX of the "A" end affected them. The next operation is to release the necessary amount the constraint corresponding to the displacement showing the greatest unbalance. Suppose that is the Y constraint. Then we release it until the end "A" has been displaced by an amount equal to ΔY. We now find that the X displacement is in effect no longer ΔX and the Z displacement also represents a new value. It is now apparent that each relaxation of a constraint will affect not only the "A" end displacement to which it corresponds but also the displacements of the "A" end in the other two coordinate directions. NOW IF AT EVERY OPERATION WE LET THE CONSTRAINT CORRESPONDING TO THE DIRECTION OF THE DISPLACEMENT SHOWING THE GREATEST UNBALANCE BE RELEASED TO THE POINT WHERE THE NECESSARY FORCE IS APPLIED TO CORRECT THE UNBALANCE, THEN THE TOTAL AMOUNT OF UNBALANCE OF THE SYSTEM WILL SOON BE REDUCED TO A NEGLIGIBLE AMOUNT. Also if an account was kept of the transfer of force increments from the constraints to the pipe, we could add up the increments corresponding to each coordinate direction and find the approximate values of P, Q, and N. In effect that is what the relaxation method does in this application.

With this preliminary picture in mind we can proceed with the explanation of the numerical solution for the reaction forces of the pipe of Figure 1.

The equations 1, 2, and 3, with the values for the coefficients of the pipe substituted into them are:

$$1.\ +602{,}677\,P - 148{,}720\,Q - 34{,}142\,N = 249{,}418{,}000$$
$$2.\ -148{,}720\,P + 242{,}463\,Q + 5{,}316\,N = 611{,}197{,}000$$
$$3.\ -34{,}142\,P + 5{,}316\,Q + 774{,}023\,N = 287{,}580{,}000$$

The product of the pipe sectional moment of inertia and the modulus of elasticity have been included with the displacements on right side of the above equations as a matter of convenience.

OPERATIONS TABLE

Operation	Nature of Operation	Equation No. 1	Equation No. 2	Equation No. 3
1 (a)	P = 1	+ 602,677 = + β_3	− 148,720 = − β_2	− 34,142 = − β_1
1 (b)	P = 1.659	+ 1,000,000	− 246,726	− 56,642
2 (a)	Q = 1	− 148,720 = − β_2	+ 242,463 = + λ_2	+ 5,316 = − α_2
2 (b)	Q = 4.124	− 613,321	+ 1,000,000	+ 21,923
3 (a)	N = 1	− 34,142 = − β_1	+ 5,316 = − α_2	+ 774,023 = + α_1
3 (b)	N = 1.292	− 44,111	+ 6,868	+ 1,000,000

FIGURE 2.

The first step towards the solution of equations 1, 2, and 3, was the preparation of the operations table Figure 2. Here the coefficients of the forces of each equation are arranged vertically so that the coefficients of any particular force appears on a separate horizontal line. The operation line 1(a) represents the values of the product of P times its coefficient for each equation when P is set equal to one. Line 1(b) represents the product of P times its coefficient for each equation when P is set equal to 1.659. The value of P for operation 1(b) was made to have the value necessary for the product of it and the P coefficient on the diagonal to equal 1,000,000.* The reason for the arbitrary choice of 1,000,000 for this number will become apparent when the relaxation table is explained. The preparation of operations 2(b) and 3(b) for Q and N were made as 1(b) was for P.

Referring now to Figure 3 it will be noted that the values of EI ΔX, EI ΔY, and EI ΔZ are entered in their respective columns on line one. The largest of these numbers is EI ΔY which equals $-$ 611,197,000. Now it will be noted from Figure 2 that operation 2(b) has the value 1,000,000 in the column that corresponds to the equation of EI ΔY. If we multiply the three numbers of operation 2(b) by 611.197 and add each of these numbers to the respective values of EI ΔX, EI ΔY, and EI ΔZ then the value of $-$ 611,197,000 will be completely liquidated. This was done on lines 2 and 3 of Figure 3. It will be noted that residual values of $-$ 624,278,000 and $-$ 274,181,000 are left on line 3 in the columns of equation 1 and equation 3 respectively as a result of this first relaxation. The largest of these corresponds to EI ΔX. The (b) operation of Figure 2 that has a value of 1,000,000 in the equation column corresponding to EI ΔX is 1(b). In order to liquidate the value $-$ 624,278,000 the operation 1(b) must be multiplied by the multiplier $+$ 624.278. This was done and entered on line 4 of Figure 3. Lines 3 and 4 of the equation columns of Figure 3 were then added to get the residual values left from the second relaxation. This process is repeated untll the residual values are reasonably small in comparison with the numbers being liquidated.

---

* The term diagonal in reference to an axisymmetric set of simultaneous equations refers to the coefficients forming a dividing line between the symmetric halves of the equation. For example:

$$K_{11}x + K_{13}y - A_1 = 0$$
$$K_{31}x + K_{33}y - A_3 = 0$$
Where $K_{31} = K_{12}$

Coefficients K_{11} and K_{33} are on the diagonal.

RELAXATION TABLE

Line No.	Operation	Multiplier	Corresponds to Equation No. 1	Corresponds to Equation No. 2	Corresponds to Equation No. 3
			Value of EIΔX to be liquidated	Value of EIΔY to be liquidated	Value of EIΔZ to be liquidated
1			− 249,418,000	− 611,197,000	− 287,580,000
2	2 (b)	+ 611.197	− 374,860,000	+ 611,197,000	+ 13,399,000
3			− 624,278,000	0	− 274,181,000
4	1 (b)	+ 624.278	+ 624,278,000	− 154,026,000	− 35,360,000
5			0	− 154,026,000	− 309,541,000
6	3 (b)	+ 309.541	− 13,654,000	+ 2,126,000	+ 309,541,000
7			− 13,654,000	− 151,900,000	0
8	2 (b)	151.9	− 93,163,000	+ 151,900,000	+ 3,330,000
9			− 106,817,000	0	+ 3,330,000
10	1 (b)	106.817	+ 106,817,000	− 26,355,000	− 6,050,000
11			0	− 26,355,000	− 2,720,000
12	2 (b)	26.355	− 16,164,000	+ 26,355,000	+ 578,000
13			− 16,164,000	0	− 2,142,000
14	1 (b)	16.164	+ 16,164,000	− 3,988,000	− 916,000
15			0	− 3,988,000	− 3,058,000
16	2 (b)	3.988	− 2,446,000	+ 3,988,000	+ 87,000
17			− 2,446,000	0	− 2,971,000
18	3 (b)	2.971	− 131,000	+ 20,000	+ 2,971,000
19			− 2,577,000	+ 20,000	0
20	1 (b)	2.577	+ 2,577,000	− 636,000	− 146,000
21			0	− 616,000	− 146,000

FIGURE 3.

The last step in the relaxation process is the adding up of the force increments. It will be noted from Figure 2 that operation 1(b) corresponds to force P and in operation 1(b) P equaled 1.659. The force of P is then equal to the sum of the multipliers in Figure 3 of operation 1(b) times 1.659. The other two forces were computed in a similar fashion.

$$P = 1.659\,(624.278 + 106.817 + 16.164 + 2.557 = 1{,}244\ \#$$
$$Q = 4.124\,(611.197 + 151.900 + 26.355 + 3.988 = 3{,}272\ \#$$
$$N = 1.292\,(309.541 + 2.971) = 404\ \#$$

The exact solution of equations 1, 2 and 3 gave P = 1245, Q = 3276, and N = 403. The relaxation process was carried out further in this case than the accuracy of the data warranted in order to illustrate the method. Values within one or two per cent of the exact values appear to be within the limits of reasonable accuracy since the values of the modulus of elasticity and the pipe wall thickness are generally known to vary somewhat from the values assumed correct.

FIGURE 3.

This solution represents the relaxation method in its simplest form. In general it will be found advantageous to apply special operations of the type termed group relaxations in Reference (a) to large systems of equations. A simple application of this device is illustrated in Figures 4 and 5 which also represents the solution of equations (1), (2) and (3).

Group relaxation in its simplest form is the combination by superposition of fundamental operations such as 1(a), 2(a), and 3(a) of Figures 2 and 4 to make special operations such as 4(a) and 5(a) of Figure 4. There is no universal rule for making new operations except that the result desired is for the residual numbers in the relaxation table to be as small as possible after the use of each operation. Refering now to Figure 4 operations 1(a), 2(a), 3(a) and 3(b) are the same as they were in Figure 2. Operation 4(a) is made by adding operations 1(a) and 2(a). Operation 5(a) is made by adding operation 1(a) to three times operation 2(a). The result desired in devising these two operations was an arrangement of signs that would reduce the residual values in the relaxation table as much as possible and at the same time retain the largest value on the diagonal of the operations table.

The mechanics of relaxation in Figure 5 was the same as formerly except that operations 3(b), 4(b) and 5(b) were used

OPERATIONS TABLE

Operation	Nature of Operation	Equation No. 1	Equation No. 2	Equation No. 3
1 (a)	P = 1	+ 602,677 = + β_3	− 148,720 = − β_2	− 34,142 = − β_1
2 (a)	Q = 1	− 148,720 = − β_2	+ 242,463 = + λ_2	+ 5,316 = − α_2
3 (a)	N = 1	− 34,142 = − β_1	+ 5,316 = − α_2	+ 774,023 = + α_1
3 (b)	N = 1.292	− 44,111	+ 6,868	+ 1,000,000
4 (a)	P = Q = 1	+ 453,957	+ 93,743	− 28,826
4 (b)	= 2.2029	+ 1,000,000	+ 206,506	− 63,500
5 (a)	P = 1 Q = 3	+ 156,517	+ 578,669	− 18,826
5 (b)	= 1.7281	+ 270,477	+ 1,000,000	− 32,533

FIGURE 4.

RELAXATION TABLE

Line No.	Operation	Multiplier	Corresponds to Equation No. 1	Corresponds to Equation No. 2	Corresponds to Equation No. 3
			Value of EIΔX to be liquidated	Value of EIΔY to be liquidated	Value of EIΔZ to be liquidated
1			− 249,418,000	− 611,197,000	− 287,580,000
2	5 (b)	+ 611.2	+ 165,316,000	+ 611,200,000	− 19,884,000
3			− 84,102,000	+ 3,000	− 307,464,000
4	3 (b)	+ 400.0	− 17,644,400	+ 2,747,200	+ 400,000,000
5			− 101,746,000	+ 2,750,000	+ 92,536,000
6	4 (b)	+ 101.7	+ 101,700,000	+ 21,002,000	− 6,458,000
7			− 46,000	+ 23,752,000	+ 86,078,000
8	3 (b)	− 86.1	+ 3,798,000	− 591,000	− 86,100,000
9			+ 3,752,000	+ 23,161,000	− 22,000
10	5 (b)	− 23.2	− 6,275,000	− 23,200,000	+ 755,000
11			− 2,523,000	− 39,000	+ 733,000
12	4 (b)	+ 2.52	+ 2,520,000	+ 520,000	− 160,000
13			− 3,000	+ 481,000	+ 573,000

FIGURE 5.

OPERATIONS TABLE

Operation	Nature of Operation	Equation "A"	Equation "B"	Equation "C"
a_x	$x = 1$	K_{11}	K_{21}	K_{31}
a_y	$y = 1$	K_{12}	K_{22}	K_{32}
a_z	$z = 1$	K_{13}	K_{23}	K_{33}
O'_x	$a_x + a_y + a_z$	$K_{11} + K_{12} + K_{13}$	$K_{21} + K_{22} + K_{23}$	$K_{31} + K_{32} + K_{33}$
O_x	$(a_x + a_y + a_z)\, C_x$ Where $+x = +y = +z = C_x$	$C_xK_{11}+C_xK_{12}+C_xK_{13}$	$C_xK_{21}+C_xK_{22}+C_xK_{23}$	$C_xK_{31}+C_xK_{32}+C_xK_{33}$
O'_y	$a_x - a_y - a_z$	$K_{11} - K_{12} - K_{13}$	$K_{21} - K_{22} - K_{23}$	$K_{31} - K_{32} - K_{33}$
O_y	$(a_x - a_y - a_z)\, C_y$ Where $+x = -y = -z = C_y$	$C_yK_{11}-C_yK_{12}-C_yK_{13}$	$C_yK_{21}-C_yK_{22}-C_yK_{23}$	$C_yK_{31}-C_yK_{32}-C_yK_{33}$
O'_z	$-a_x + a_y - a_z$	$-K_{11} + K_{12} - K_{13}$	$-K_{21} + K_{22} - K_{23}$	$-K_{31} + K_{32} - K_{33}$
O_z	$(-a_x + a_y - a_z)\, C_z$ Where $-x = +y = -z = C_z$	$-C_zK_{11}+C_zK_{12}-C_zK_{13}$	$-C_zK_{21}+C_zK_{22}-C_zK_{23}$	$-C_zK_{31}+C_zK_{32}-C_zK_{33}$

FIGURE 6.

and complete liquidation of one of the residual numbers by each operation was not made.

The process of determining the values of the unknowns from special operations is simple but not too apparent. Since N corresponds to operation 3(b) and 3(b) was not involved in the special operations 4(b), and 5(b) it can be solved for as before.

$$N = 1.292\ (+\ 400 - 86.1) = +\ 406 \text{ Pounds}$$

The multipliers of 5(b) and 4(b) from the relaxation table are separately added and multiplied by the constants from the column "Nature of Operation" of Figure 4 as formerly.

$$4(b)\quad 2.203\ (+\ 101.7 + 2.52) = 229.59$$
$$5(b)\quad 1.728\ (+\ 611.2 - 23.2) = +\ 1{,}016.12$$

Since P = 1 corresponds to 1(a) and operation 1(a) is involved in both operations 4(b) and 5(b) it will be seen from the "Nature of Operations" column of Figure 4 that:

$$P = +\ 229.59 + 1{,}016.12 = +\overline{1{,}246} \text{ pounds,}$$

and by the same argument:

$$Q = +\ 229.59 + 3(1{,}016.12) = +\ 3{,}278 \text{ pounds}$$

The mechanics of the special operations of group relaxation are better understood if we use an example in which the identity of the constants are apparent in the solution. Let the following simultaneous equations represent an axisymmetric set with x, y, z as the unknowns.

$$(A)\quad K_{11}x + K_{12}y + K_{13}z - A_1 = O$$
$$(B)\quad K_{21}x + K_{22}y + K_{23}z - A_2 = O$$
$$(C)\quad K_{31}x + K_{32}y + K_{33}z - A_3 = O$$

The operations table, Figure 6, was set up with a_x, a_y, and a_z representing the fundamental operations. O'_x, O'_y, and O'_z represent combinations of fundamental operations as indicated in the "Nature of Operations" column. Operation O_x is equal to operation O'_x multiplied by constant C_x. Constant C_x is a number of the magnitude necessary to raise the number $(K_{11} + K_{12} + K_{13})$ to some even multiple of ten as a matter of convenience in computation.*

* For example in Figure 4 the number 1.7281 raises 578,669 of operation 5(a) to 1000,000 in operation 5(b).

RELAXATION TABLE

Operation	Multiplier	Corresponds to Equation (1)
		$-A_1$
O_x	Σr	$C_x\Sigma rK_{11} + C_x\Sigma rK_{12} + C_x\Sigma rK_{13}$
		$C_x\Sigma rK_{11} + C_x\Sigma rK12 + C_x\Sigma rK_{13} - A_1$
O_y	Σs	$C_y\Sigma sK_{11} - C_y\Sigma sK_{12} - C_y\Sigma sK_{13}$
		$C_x\Sigma rK_{11} + C_x\Sigma rK_{12} + C_x\Sigma rK_{13} + C_y\Sigma sK_{11} - C_y\Sigma sK_{12} - C_y\Sigma sK_{13} - A_1$
O_z	Σt	$-C_z\Sigma tK_{11} + C_z\Sigma tK_{12} - C_z\Sigma tK_{13}$
		$K_{11}(C_x\Sigma r + C_y\Sigma s - C_z\Sigma t) + K_{12}(C_x\Sigma r - C_y\Sigma s + C_z\Sigma t) + K_{13}(C_x\Sigma r - C_y\Sigma s - C_z\Sigma t) - A_1 = O$

FIGURE 7.

Constant C_y raises ($K_{21} - K_{22} - K_{23}$) to some even multiple of ten, and C_z raises ($- K_{31} + K_{32} - K_{33}$) to an even multiple of ten.

The special operations O_x, O_y, and O_z were used in the relaxation table of Figure 7. The multipliers Σr, Σs, and Σt represent the sum of the multipliers of O_x, O_y, and O_z repsectively that were necessary to completely liquidate $- A_1$, $-A_2$, and $- A_3$. Since this is stipulated, only the first three columns of the complete relaxation table are included in Figure 7 for the purposes of this example. The residual number left, in Figure 7, after complete liquidation is $K_{11}(C_x \Sigma r + C_y \Sigma s - C_z \Sigma t) + K_{12}(C_x \Sigma r - C_y \Sigma s + C_z \Sigma t) + K_{13}(C_x \Sigma r - C_y \Sigma s - C_z \Sigma t) - A$, which therefore equals zero. By comparison with equation (A) it is evident that:

$$x = C_x \Sigma r + C_y \Sigma s - C_z \Sigma t$$
$$y = C_x \Sigma r - C_y \Sigma s + C_z \Sigma t$$
$$z = C_x \Sigma r - C_y \Sigma s - C_z \Sigma t$$

An inspection of these identities will show that the key to the addition of the products of the "C" constants and the respective sums of the multipliers (i.e.: $C_x \Sigma r$, $C_y \Sigma s$, $C_z \Sigma t$) to get the numerical values of the unknowns lies in the way the fundamental operations were used to make the special operations. For example a_x of the O_x operation corresponds to $C_x \Sigma r$ and a_x of O_y operation corresponds to $C_y \Sigma s$ and $- a_x$ of the O_z operation corresponds to $- C_z \Sigma t$ and x equals the sum of these products as shown above.

As a practical example on the use of group relaxations for the solution of a simultaneous set of equations, a system of six equations was chosen representing the rotations and translations of the junction point of a three branch pipe that is anchored at the ends.

(1) $- 25.330{,}29\ \delta x - 1.387{,}83\ \delta y + 13.681{,}20\ \delta z - 0.011{,}81\ \psi x - 0.381{,}61\ \psi y - 0.013{,}20\ \psi z - 16{,}687.356 = O$

(2) $- 1.387{,}83\ \delta x - 24.639{,}14\ \delta y + 18.002{,}07\ \delta z + 0.684{,}17\ \psi x - 1.085{,}62\ \psi y + 0.070{,}98\ \psi z + 21{,}039.912 = O$

(3) $+ 13.681{,}20\ \delta x + 18.002{,}07\ \delta y - 71.484{,}01\ \delta z - 0.697{,}42\ \psi x + 1.937{,}87\ \psi y + 0.137{,}93\ \psi z + 1{,}706.189 = O$

(4) $- 0.011{,}81\ \delta x + 0.684{,}17\ \delta y - 0.697{,}42\ \delta z - 0.051{,}41\ \psi x + 0.031{,}27\ \psi y + 0.000{,}19\ \psi z - 622.222 = O$

OPERATIONS TABLE

Operation	Nature of Operation	From Equation 1	From Equation 2	From Equation 3	From Equation 4	From Equation 5	From Equation 6
1 (a)	$\delta x = 1$	− 25.330,29	− 1.387,83	+ 13.681,20	− 0.011,81	− 0.381,61	− 0.013,20
2 (a)	$\delta y = 1$	− 1.387,83	− 24.639,14	+ 18.002,07	+ 0.684,17	− 1.085,62	+ 0.070,98
3 (a)	$\delta z = 1$	+ 13.681,20	+ 18.002,07	− 71.484,01	− 0.697,42	+ 1.937,87	+ 0.137,93
4 (a)	$\psi x = 1$	− 0.011,81	+ 0.684,17	− 0.697,42	− 0.051,41	+ 0.031,27	+ 0.000,19
5 (a)	$\psi y = 1$	− 0.381,61	− 1.085,62	+ 1.937,87	+ 0.031,27	− 0.129,03	+ 0.006,08
6 (a)	$\psi z = 1$	− 0.013,20	+ 0.070,98	+ 0.137,93	+ 0.000,19	+ 0.006,08	− 0.026,09
A	$-4\delta x = \delta y = .1\,\delta z = 1$	+101.301,46	− 17.287,62	− 43.871,13	+ 0.661,66	+ 0.634,63	+ 0.137,58
	$= .987,153$	+100.000,00	− 17.065,53	− 43.307,52	+ 0.653,16	+ 0.626,47	+ 0.135,81
B	$-\delta x = 4\,\delta y = \delta z = 1$	+ 33.460,18	− 79.166,65	− 13.156,93	+ 2.051,06	− 2.022,99	+ 0.435,07
	$= 1.263,158$	+ 42.265,49	−100.000,00	− 16.619,28	+ 2.590,81	− 2.555,36	+ 0.549,56
C	$-\delta x = \delta y = \delta z = 1$	+ 37.623,66	− 5.249,24	− 67.163,14	− 0.001,44	+ 1.233,86	+ 0.222,12
	$= 1.488,912$	+ 56.018,32	− 7.815,65	−100.000,00	− 0.002,15	+ 1.837,11	+ 0.330,71
D	$-10\psi x = \psi y = -\psi z = 1$	− 0.250,32	− 7.998,28	+ 8.774,14	+ 0.545,20	− 0.447,78	+ 0.030,29
	$= 1.834,189$	− 0.459,13	− 14.670,36	+ 16.093,43	+ 1.000,00	− 0.821,31	+ 0.055,56
E	$-\psi x = 10\psi y = \psi z = 1$	− 3.817,53	− 11.469,37	+ 20.214,01	+ 0.364,27	− 1.315,45	+ 0.034,53
	$= .760,196$	− 2.902,07	− 8.718,97	+ 15.366,61	+ 0.276,92	− 1.000,00	+ 0.026,25
F	$-\psi x = \psi y = -100\psi z = 1$	+ 0.950,20	− 8.868,09	− 11.158,11	+ 0.063,88	− 0.768,40	+ 2.614,69
	$= .382,455$	+ 0.363,41	− 3.391,65	− 4.267,47	+ 0.024,43	− 0.293,88	+ 1.000,00

FIGURE 8.

$$(5) \quad -0.381{,}61\,\delta x - 1.085{,}62\,\delta y + 1.937{,}87\,\delta z + 0.031{,}27\,\psi x - 0.129{,}03\,\psi y + 0.006{,}08\,\psi z + 1{,}083.196 = O$$

$$(6) \quad -0.013{,}200\,\delta x + 0.070{,}98\,\delta y + 0.137{,}93\,\delta z + 0.000{,}19\,\psi x + 0.006{,}08\,\psi y - 0.026{,}09\,\psi z - 122.942 = O$$

The operations table of Figure 8 was made from these equations, and operations A, B, C, D, E, and F were used in the relaxation table. In order to save space only a summary of the relaxation table is given in Figure 9. The actual sequence of operations was: B × 75; A × 75; E × 1000; C × 150; E × 250; C × 30; F × (−20); D × 40; C × (− 10); B × (− 4.5); A × 3; F × 2; E × (− 6); B × (− 0.5); A × 0.5; D × 10; E × (− 10); A × (− 0.34); B × (− 0.5); E × (− 5); C × (− 1); E × 1.202; A × 0.624; D × 1.141.

The products of the sums of the multipliers and the constants from the operations table were:

$$\begin{aligned}
&(A) \quad .987{,}153 \times (+\ 78.780) = +\ 77.768\\
&(B) \quad 1.263{,}158 \times (+\ 69.800) = +\ 88.168\\
&(C) \quad 1.488{,}912 \times (+ 169.200) = + 251.924\\
&(D) \quad 1.834{,}189 \times (+\ 51.141) = +\ 93.802\\
&(E) \quad .760{,}196 \times (+\ 1{,}229) = + 934.281\\
&(F) \quad .382{,}455 \times (-\ 16{,}798) = -\ 6.424
\end{aligned}$$

The additions of these products to obtain the values of the unknowns are as follows:

$$\begin{aligned}
\delta x &= -(4 \times 77.768) - 88.168 - 251.924 = -651\\
\delta y &= +77.768 + (4 \times 88.168) + 251.924 = +682\\
\delta z &= +(0.1 \times 77.768) + 88.168 + 251.924 = +348\\
\psi x &= -(10 \times 93.802) - 934.281 - 6.424 = -1866\\
\psi y &= +93.802 + (10 \times 934.281) - 6.424 = +9430\\
\psi z &= -93.802 + 934.281 - (-100 \times 6.424) = +1483
\end{aligned}$$

In general the rapidity of convergence of a given set of equations can be greatly accelerated if the computer is skilful in: devising special operations when making the operation table; extrapolation when using the operations in the relaxation table.

The degree of exactness of solutions with the relaxation process depends only on the number of relaxations carried out. However a mathematically exact solution will never quite be reached

SUMMARIZED RELAXATION TABLE

Operation	Summ. of Multipliers	Equation 1	Equation 2	Equation 3	Equation 4	Equation 5	Equation 6
		− 16,687.356	+ 21,039.912	+ 1,706.189	− 622.222	+ 1,083.196	− 122.942
A	+ 78.78	+ 7,878.000	− 1,344.422	− 3,411.767	+ 51.456	+ 49.353	+ 10.699
B	+ 69.8	+ 2,950.131	− 6,980.000	− 1,160.026	+ 180.839	− 178.364	+ 38.359
C	+ 169.2	+ 9,478.301	− 1,322.409	− 16,920.000	− 0.364	+ 310.839	+ 55.957
D	+ 51.141	− 23.481	− 750.257	+ 823.034	+ 51.141	− 42.003	+ 2.841
E	+ 1,229	− 3,566.644	− 10,715.613	+ 18,885.564	+ 340.335	− 1,229.000	+ 32.262
F	− 16.798	− 6.105	+ 56.973	+ 71.685	− 0.410	+ 4.937	− 16.798
Residual values		+ 22.846	− 15.816	− 5.321	+ 0.775	− 1.042	+ 0.378

FIGURE 9.

When the slide rule is being used for this work and the relaxation table is extensive it is advisable to sum the multipliers of each operation and use the sums as starting multipliers in a new relaxation table. This is because small inaccuracies are additive in the relaxation table.

Probably the most attractive feature of this method is that the experience gained from similar problems can be utilized in shortening the solution. When approximate or even very rough values of the unknowns are known a few steps of the relaxation procedure will be sufficient to obtain new values of a high degree of accuracy.

The mathematical proof of this successive approximation method shows that it is convergent and approaches the unknowns as a limit. Such proof can be found in chapter 5 of reference (a) and in reference (g).

The application as presented in this paper is somewhat elementary. It is believed that future development of the method especially in regard to "Group" relaxations will further reduce the labor involved in pipe flexibility calculations.

References.

(a) "Relaxation Methods in Engineering Science," by R. V. Southwell. Published by Oxford at the Clavendon Press in 1940.

(b) "Thermal Expansion Stresses in Piping," by Mason S. Noyes. May 1941 JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

(c) "A Simplification in the Meyer-Hovgaard System of Pipe Stress Forms," by W. E. Bleick, November 1941 JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.

(d) "Graphical Analysis of Pipe Stresses," by A. Osbourne. Volume 47 (1939) Transactions of the Society of Naval Architects and Marine Engineers.

(e) "Piping Stress Calculations Simplified," by S. W. Spielvogel. McGraw-Hill Book Co. 1943.

(f) "Design of Piping Systems." The M. W. Kellogg Company 1941.

(g) "The General Theory of Relaxation Methods Applied to Linear Systems," by G. Temple. Proceedings of the Royal Society of London. Volume 169 (1939).

MAGNETIC POWDER INSPECTION AND ITS PRACTICAL APPLICATION.

By J. W. Jenkins* and K. D. Williams**.

Magnetic Powder Inspection has been greatly popularized during the period of increased production of steel forgings, castings and fabricated parts required for waging the present war. Incident to the extention of its use and the frequent necessity for employing operators who have insufficient experience and whose judgment is therefore not at all times reliable, certain misconceptions and even abuses have occurred in its application. It is fundamentally an "inspection tool" and although its principles and varied equipment and procedures are well known, it may be well at the outset to state briefly some of the variables which may be involved in its use.

Primarily, Magnetic Powder Inspection is a non-destructive method of detecting surface metallic discontinuities in ferrous materials, that is, materials which are susceptible to magnetizing. The procedure consists of magnetizing the part under inspection and then flowing a wet suspension of paramagnetic particles, or dusting, or lightly blowing mobile dry paramagnetic particles onto the surface. Metallic discontinuities tend to form leakage flux fields or flux disturbances into which the particles align themselves and thereby outline or indicate the defect.

Magnetizing is accomplished by using direct current, rectified alternating current or alternating current. Current may be applied directly to the part to be magnetized or passed through coils placed longitudinally around the part or at 90 degree or other angle to its axis for purposes of indicating defects expected to exist in various positions. Four hundred (400) amperes flowing in the part itself or in a single conductor represents 400 ampere

* Principal Materials Engineer, Research & Standards Branch, Bureau of Ships, Navy Department.

** Chief Materials Engineer, Research & Standards Branch, Bureau of Ships, Navy Department.

turns. The use of 4 turns of cable carrying 100 amperes or 100 turns carrying 4 amperes represents 400 ampere turns.

Again, basically, as the flux field is at 90 degrees to the magnetizing current and as maximum powder "build up" parallels the flux field, the direction of magnetizing current for optimum indication should be parallel to the longitudinal direction of the expected defect. This applies whether the current is passed through the part or magnetizing is accomplished by the use of coils.

The powder may be applied while the magnetizing current is flowing or residual magnetism may be sufficient. The necessary current value or ampere turns to properly magnetize varies with such factors as the diameter, shape, mass, susceptibility of the part to magnetizing and the type, size, and location of the defect.

Cracks, inclusions, sandsplits, folds, laps, etc., will all be indicated in a similar manner depending upon the conditions. Over magnetizing, sharp section changes, stress gradients, localized flux concentrations and other reasons, may cause paramagnetic particle patterns to form. It is perfectly conceivable that a flux concentration formed by drawing a fine nail along the surface of a part might simulate the indication of a thermal crack existing in the part. It is, therefore, not only necessary that careful consideration be given to proper correlation of all the factors involved in whatever procedure is adopted but that its use be limited to the scope which Magnetic Powder Inspection can encompass.

To quote from a paper presented by W. C. Stewart, Technical Advisor of the American Institute of Bolt, Nut and Rivet Manufacturers speaking on the present subject before the Aircraft Fasteners Division of the Institute held in Cleveland on May 5, 1944.

"The collection of magnetic powder into lines on the surface of a magnetized material is only the indication of a disturbance to the flow of magnetic flux through the part, such as may be caused by a sharp corner, a crack, an inclusion, or a fold in the metal. It is not a quantitative measurement of the extent of the disturbance, nor is it even a qualitative indication of the type of the disturbance, except possibly to some extent in the hands of a person thoroughly experienced in the use of the process and in the type of defect probable in the part in question; and even he can't be too sure. That this is true is shown by reports that

certificates from nine testing laboratories enumerating defective blots (as determined by magnetic inspection) found in the same lot of blots, varied from 0.6 per cent defective to 17.5 per cent defective; and no two of the nine laboratories reported identical results. By the very nature of the magnetic testing process, therefore, its proper use is confined principally to the preliminary location of possible imperfect parts or the specific location of a defect in a suspected part. The determination of whether a part showing magnetic indications is really defective or not should be made by subsequent metallurgical and physical examination to determine the type of imperfection, the extent of the imperfection, and the effect of the imperfection on the ability of the part to perform its function in service".

Considering that Magnetic Powder Inspection is a method of pointing to what may be a harmful defect and without attributing to it the ability to either qualitatively or quantitatively measure the defect indicated it can be said that it has been and is a very useful tool in non-destructive inspection of forgings, castings, bars, etc.

Sub-surface Defects.

Magnetic Powder Inspection has been found to be particularly useful in the field of welding, to indicate defects which are sub-surface. Under like magnetization sub-surface indications vary from similar surface defect indications.

A large commercial shipbuilding concern has reported on the use of Magnetic Powder Inspection to detect surface and sub-surface defects in butt welds used in fabricating mild steel piping of ⅜ inch to ½ inch wall, for 400# - 750 degrees F ships' steam lines. Of particular interest is the dry powder inspection of 1263 welds on 433 pieces of pipe. Among the sub-surface defects located were 25 very near the surface that filed out, 20 gas pockets that when filed out required rewelding, 5 slag inclusions which might have caused failure in service, 3 cracks that were ultimately traced to laminations in the weld neck flanges and two bad cases of pin holes. Chill rings were used with intermittent guides spot welded to the rings. The rings were slightly oversize and fitted to individual pipes. The welds were performed in 3 passes and built up slightly on the pipe and then ground by means of a portable grinder with flexible shaft. Preheat of 300 to 400

degrees F. was employed. The grind was followed by stress relieving at 1150 degrees F. Magnetic Powder Inspection was performed in a flat position after stress relieving, the pipe being rotated by chain falls. Contactors in adjustable heads were brought to points about 4 to 5 inches apart, one adjacent to each side of the weld for each investigation and this procedure repeated by rotating the pipe. Contact was maintained by spring pressure and the inspector was free to evenly apply a smooth cloud of the contrasting gray magnetic powder. The pipe was lightly tapped with a hammer until the circular patterns of the fields around the contacting "Prods" were indicated. From 250 to 175 amperes were supplied continuously from a 300 ampere D.C. welding machine, the open circuit voltage of which was 60. After the field patterns were formed around the "Prods" a careful search of the pattern for even the most minute irregularity was made by the inspector. When any irregularity was noted the powder was removed and reapplied. If the irregularity persisted on subsequent powder applications it was investigated by light grinding to determine its cause. In this manner, the sub-surface defects were found. Surface indications were found immediately and with ease. It was stated that grinding and powder inspection of a weld on a 5 inch pipe required about 45 minutes.

It is noteworthy that in applying the method to sub-surface defects it was used only as a pointer to indicate that some defect existed. The qualitative as well as the quantitative aspects of the defect were determined by grinding and then rewelding was employed to correct repairable defects.

In replying to the paper by W. C. Stewart from which the foregoing quotation was taken, Mr. W. E. Thomas of the Magnaflux Corporation writes an interesting challenge to Industry (Fasteners Vol. 1. No. 3) from which the following pertinent statements are quoted:

"A few months ago W. C. Stewart stated that something was wrong with magnetic particle inspection because a certain quantity of bolts was sent to several different inspection departments or laboratories one after the other to see how many would fail in this inspection, and widely different percentages were rejected.

This discouraging and seemingly inaccurate result is not damning to the method but is damning to those who sent the bolts and

to those who inspected them, for the probabilities are that those who sent them did not also send the standards of acceptance, and those who inspected tried to guess at suitable standards and their guesses were widely divergent.

The manufacturer is entitled to know—yes, he must know—the standards of acceptance of his customer. If too severe, he should attempt to have those standards broadened. The bolt industry has good inspectors, metallurgists, and engineers. Much of the knowledge of bolt design and use lies with them. There is a challenge to the industry to educate others, to see that inspection is only for true defects which may contribute to service failures; but the selling of such ideas must be backed up by facts and these facts are only obtainable by an investigation of some breadth."

Much has been and can be written on what not to do about Magnetic Powder Inspection. It has been the experience of the authors that the dont's become involved in the picture only when (a) either the details of the procedure are inadequate or (b) the operator is improperly instructed or (c) the attempt is made to raise the objective beyond the stage of "pointing out a possible defect" to a qualitative and/or quantitative delineation of that defect, by viewing the indication caused by its presence and then attempting to either accept or reject the part on the appearance of the indication.

Many futile attempts have been made to generalize procedures to cover all types of equipment for magnetizing and demagnetizing, using all types of current both for continuous and residual magnetism by direct application of the current to the part or by induction, during powder application either by wet or dry method; covering both surface and sub-surface defects or blemishes on all sizes and shapes of all types of materials. Obviously, general process specifications can be only mildly suggestive of what to do in any specific case.

However, by breaking down the application to specific instructions for the inspection of restricted sizes and/or shapes of limited classes of objects it becomes rather a simple matter to eliminate controversy and confusion and to arrive at very useful results from Magnetic Powder Inspection.

In fact by just such common sense procedure has it been practicable to apply Magnetic Powder Inspection to much of the

record tonnage of machinery and hull parts that has gone into the building of the most colossal Navy the world has ever seen.

Thousands of Magnetic Powder Inspections have been and are being successfully accomplished because:

(1) Understandable specific procedures have been developed for the inspection of specific articles. The instructions issued are free from generalizations and apply to the size shape, and mass of the part involved as well as to the quantity of parts involved and to the character of the defect to be considered.

(2) Much thought has been given to the development of equipment which can and does encompass the inspection problems involved.

(3) Schools for the training of operators have turned out hundreds of competent people while many Government activities as well as industrial plants have trained many more.

(4) Broad research programs have been conducted to develop a clear understanding as to the definition of an acceptable imperfection and an unacceptable defect and hence criteria for acceptance or rejection based upon what is satisfactory for the purpose intended have been established.

(5) Assurances that defects are being found by a given procedure are obtained either by "proof of method" or by application of experience in selecting proper method parameters.

It is the purpose of this paper to set forth, as far as practicable within the space allotted, what in the experience of the authors are the limitations of Magnetic Powder Inspection in its practical use, and to make known some pertinent and practical results of research leading up to the establishment of rules for acceptance. It is hoped that they will be of value in the future use of Magnetic Powder Inspection.

Large propulsion forgings have held such an important place in the Naval expansion that they afford an excellent field of investigation in the search for rules of acceptance.

To assist inspectors in formulating decision as to acceptability it has been necessary first to classify into types the defects too

often found or indicated on the surface of machined forgings. These defects fall into the following general classes:

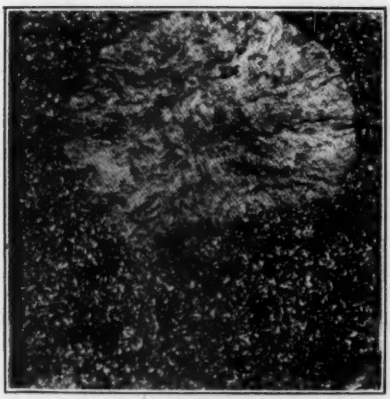
Flakes (Thermal cracks)
Seams and laps
Slag inclusions and sand splits
Other non-metallic inclusions
Pipes or bursts

Before defining or discussing the relative effects of these defects upon the expected performance of the forging in service it must be pointed out that for the purpose of the present discussion the forgings under consideration are relatively large and are stressed to but a fraction of the endurance limit of the material. Highly stressed machine parts, for example, Diesel engine parts in which the working stress may approach the endurance limit of the steel may require an entirely different criteria for acceptance. Questions as to design stresses of the part under consideration should be referred to both the design and the material engineers.

During Magnetic Powder Inspection the indications must be investigated for it is necessary to identify the type of defect. Each different type has a different effect on the serviceability of the forging.

"Flakes" are the most serious defects and appear as hair-line cracks on the machined surface of the forgings usually in the longitudinal direction. They may be very difficult to detect by visual examination, are sometimes indicated by the regular breaking of chips during finish machining, and are definitely located when exposed on the surface by proper application of Magnetic Powder Inspection. All forgings containing flakes should be rejected or referred to the proper authority for decision as to acceptability. The adjacent photograph shows a flake indicated by a ¾ inch line on the surface (top of photo) and exposed by splitting the steel piece at the crack.

"Seams" and "laps" may be serious, depending on their size and location, especially because the ends and edges of such defects terminate in a very sharp angle, which introduces a notch effect. A large proportion of these defects are often removed by machining, since they originate at the surface. Seams may be identified as longitudinal discontinuities penetrating into the steel, generally



PHOTOGRAPH OF THERMAL RUPTURE (FLAKE)
(Actual Size)
Found in 3% Nickel Steel Forging.

with a black, oxidized appearance, and often branching into two or more individual seams, sometimes locally described as "church-steeples" or "crow's-feet". "Laps" are somewhat similar, but may extend in any direction, and usually penetrate into the steel at an angle instead of vertically.

"Slag inclusions" and "sand splits" are self-explanatory terms applied to defects occasionally occurring in forgings. The seriousness of these defects varies with their size, shape, and location.

"Non-metallic inclusions" are usually apparent to the naked eye and occur in forgings as discontinuous longitudinal lines composed of a series of individual particles, or as continuous longitudinal defects which result from the elongation of inclusions which were practically round in the original ingot. These inclusions are usually round in cross section and are generally rounded. In cases where they are sharply pointed or flat in shape they may become the cause of fatigue cracks in service and should be regarded as somewhat more serious than rounded inclusions. Discontinuous inclusions are the least harmful.

There follows a recommended procedure for inspection of forgings with some comments on identification of defects.

The forging should be inspected at intervals during the machining operation, if practicable. If defects appear, or if chips break regularly at the same position at repeated revolutions of the forging, during machining, this fact may point to the location of a defect of such nature, position, or size as to make it inadvisable to proceed with further work.

Many man-hours of labor may be saved if defective forgings are discovered in the early stages of machining. Experienced machinists often note very slight deviations from the normal during machining operations. Their disclosures should be investigated, and their cooperation encouraged.

The bore of hollow forgings should be carefully examined to determine whether or not as a result of insufficient cropping, part of the shrinkage cone has been left in the forging. Such defects as porosity and large slag inclusions, are evidence of this condition, and if not completely removed, the forging may be unsatisfactory.

Most large shops have facilities for performing Magnetic Powder Inspection. In many instances its use verifies the condition

revealed by visual examination. This fact should not be reason for omitting the magnetic powder test whenever practicable. Sooner or later some serious defect may escape the most careful visual examination.

After the magnetic powder has been applied, examine the member from end to end. Examine all fillets carefully. These regions expose the material at different levels which is favorable for revealing the presence of flakes. Examine in a similar manner parts of the member having the smallest diameter. Note any tendency for the powder to pile up at a defect. This may indicate greater depth of the discontinuity. Brush away the powder where defects are indicated and examine the areas with a 10 power hand magnifier and portable light. Observe whether the discontinuities contain slag and whether the defects are narrower at the ends. These characteristics are indicative of inclusions. Draw a small file over the defect from end to end at right angles to the defect. Inclusions are often comparatively shallow and may be removed by this procedure. Repeat Magnetic Powder Inspection and note whether or not indication persists. If a sharply defined line discontinuity is located, which after light filing persists on repeating powder application, again repeat the process, and if the defect still persists, it is probably a flake or thermal crack of considerable depth.

Next, examine the ends of the forgings. The ends present transverse surfaces. Strongly defined magnetic powder indications may point to thermal cracks. Seams or laps, the contours of which are somewhat rounded, tend to give powder indications of a less concentrated form. However, it should be emphasized that powder indications are only pointers which locate defects. The defects themselves must be carefully investigated along the lines set forth above, to determine their character. Non-metallic inclusions on transverse surfaces of forgings generally appear as pock marks.

If the transverse surfaces are clear, or contain only pock marks in the magnetic powder test or on a deep etched cross section, and the previous examination has confirmed that the discontinuities are non-metallic inclusions, the useability of the forging will depend on their size, distribution, and location. Determine whether or not the most objectionable non-metallics are in regions of high or low stress. Inclusions that are objectionable in the

driving end of a rotor may not be serious if located at the unloaded end. Likewise inclusions in the bore of the torsional member are less damaging than if on the outer surface. Inclusions in regions of stress concentration, such as changes in section, are the most objectionable. If a member is a gear, the teeth surfaces should be free of inclusions.

The setting up of standard limitations for sizes and frequency of occurrence of inclusions must be tempered by specific design requirements and should be modified by the considerations in the foregoing paragraph where necessary. However, such limitations have been applied to the acceptance of inclusions in main body of forgings designed with a high factor of safety:

Shaft Surfaces Other Than Journal Areas.

Forgings with inclusions 1 inch long or less have been accepted without removing the inclusions. These defects should be investigated by filing or grinding if it is suspected they are of unusual depth. Inclusions over 1 inch long and not more than .035 inch deep have been considered acceptable, but it has ordinarily been necessary to explore most of the inclusions over 1 inch long by hand filing or grinding in order to be assured that they are not over .035 inch deep.

Surface of Journals.

Forgings with inclusions not over .010 inch deep have been considered acceptable when not more than one inclusion over 1 inch long occurred in any one journal area and all inclusions were cleaned up by filing or "Dimple grinding" so that no particles, either non-metallic or metallic could be detached in service. No inclusions have been permitted at the end of the journal in such a position that the ground area remaining after removal extends partly outside the bearing and partly inside.

Gear Tooth Surfaces.

Gear and pinion forgings should be free from inclusions on gear tooth contacting surfaces. Minor defects of this nature may be referred to the procuring agency for final decision if the inspector feels that circumstances warrant.

Inclusions which are larger in extent than allowed on shaft surfaces and other journal areas may be removed entirely, and

their total depth, length, and position, as well as details of any other defects which may be present, together with all pertinent information as to service of the parts involved, reported to the procuring agency for decision as to acceptability.

No method of repair of forgings containing objectionable inclusions is considered feasible except their removal, as indicated above. Removal by either grinding or filing should be done in such a way that the marks left by grinding or filing are at approximately right angles to the direction of the inclusion, and all edges should be carefully rounded and smoothed out.

The foregoing establishment of criteria with reference to methods of inspection and the application of common sense principles to a specific class of forgings has been selected as illustrative of the manner in which Magnetic Powder Inspection may be successfully employed. Many similar procedures and criteria have been established for many other classes of materials.

A useful method of establishing a permanent record of magnetic powder indications has been devised. This method consists of transferring the indications upon an adhesive surface. To accomplish this, either surgical adhesive tape or scotch tape may be employed. In each case the object bearing the indications is wrapped with the tape and when the tape is removed it carries the magnetic powder indications. If surgical tape is used, cellophane should be applied to the adhesive surface. If scotch tape is used, plain paper should be applied to the adhesive surface of the tape. A record of the surface of a flaked pinion and of a cross section of a pinion gear is included to illustrate this method. The section of the pinion was broken to determine the character of the defects indicated and a photograph of this section is also included.

Proof of Method.

Beginning with the earliest use of Magnetic Powder Inspection, the doubt as to whether the procedure as used was actually producing the indication of defects or whether defects just were not there has existed. The efficacy of the magnetizing means was often tested by use of a suspended nail or file or by applying the procedure to a piece of steel of comparative size known to contain defects. Gradually, certain standards were developed by experience.

How well, for example, the values of from 1600 to 2400 ampere turns were selected for propulsion shafting of from 18 to 28 inches in diameter has recently been scientifically proven by an unpublished report of the General Electric Company. That company has generously permitted the authors to extract therefrom for inclusion here. It is regretted that the report in toto cannot be given general distribution as it is an outstanding example of the type of scientific research which leads to perfection of useful processes. The investigation covered by this report was prompted by the fact that a number of different methods and equipments are used with varying success in the inspection of turbine rotor forgings and the desire to obtain "comparative data upon the application and range of limitations for the different test methods".

This data was obtained by conducting a series of magnetic powder tests on various size thermal cracks located at various diameters using different mediums and conditions of applied magnetism.

The fifteen (15) conclusions of this report are of such widespread interest that they are quoted completely below:

"1. Circular magnetization is the more effective method for magnetic particle testing of turbine rotor forgings.

2. Circular magnetization with direct currents obtained from generators, copper oxide rectifiers or storage batteries gives equivalent results.

3. D-c is more effective than A-c; it required 25 to 50 per cent more a-c to obtain equal results under all conditions of test.

4. D-c continuous method is the most sensitive and most definite for revealing surface defects.

5. D-c residual method is slightly less effective than the d-c continuous method.

6. D-c surge method is between the d-c continuous and d-c residual methods in effectiveness. Records of tests show the surge and residual patterns are practically the same for the same peak value of magnetizing current.

7. Bi-polar method (Electromagnets) may be used but it is not as effective or efficient as circular magnetization.

8. G-E magnetic and Magnaflux paste give equivalent results.

9. The wet method is more sensitive than the dry method.

10. Where the dry method is used because of surface conditions, application by power blower is recommended if test is made over large areas.

11. Application of dry powder by shaker or bulb is satisfactory if confined to small parts or isolated areas.

12. For continuous d-c method, the minimum current required is 75 amperes per inch of maximum diameter or 2000 amperes whichever is smaller.

13. For continuous a-c method, the minimum current required is 110 amperes per inch of maximum diameter or 3000 amperes whichever is smaller.

14. For d-c residual method, the minimum current required is 100 amperes per inch of maximum diameter or 3000 amperes whichever is smaller.

15. For d-c surge method, a minimum current of 90 amperes per inch of maximum diameter or a peak of 3000 amperes whichever is smaller. The peak current is applied for a few seconds and 40 per cent of the value held while test is being made."

The description and outline of tests, identification of the rotors used, procedure and selected results and figures which follow are direct quotations from the report:

"The test results presented herein were obtained on three partly machined rotors of different sizes which were rejected because of thermal cracks.* These defects were located on various parts of the rotors. Magnetic particle patterns of selected cracks were recorded upon transparent scotch tape for evidence of the indications produced.

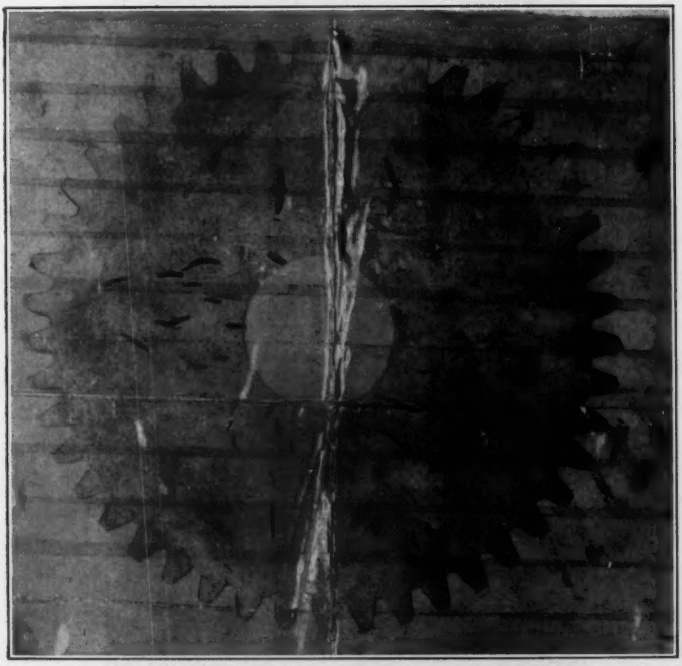
The patterns were obtained for the following conditions of test.

(A) Magnetizing currents

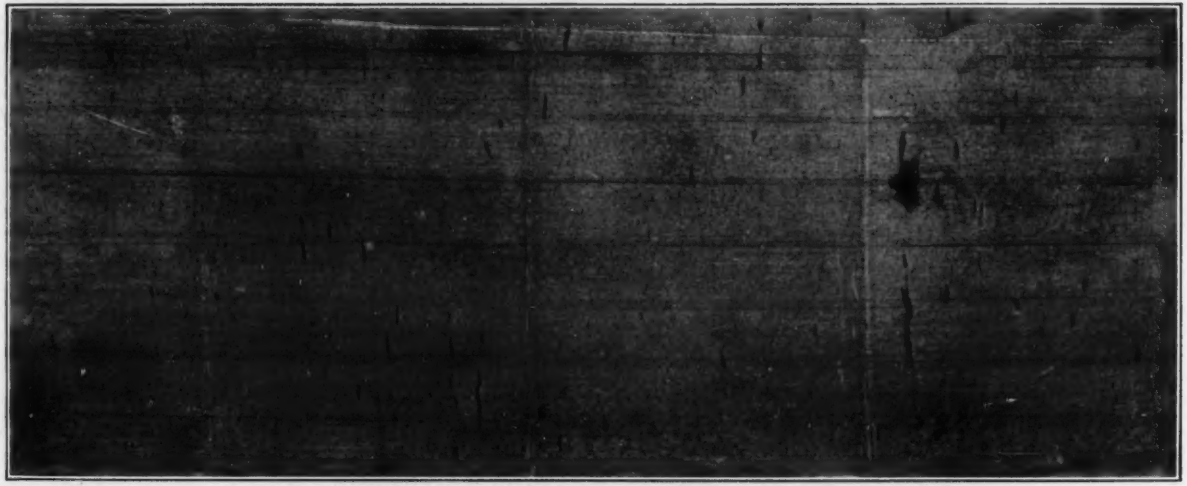
1. Alternating current (r.m.s.)
2. Direct current
   (a) Generator
   (b) Storage battery
3. Rectified current

---

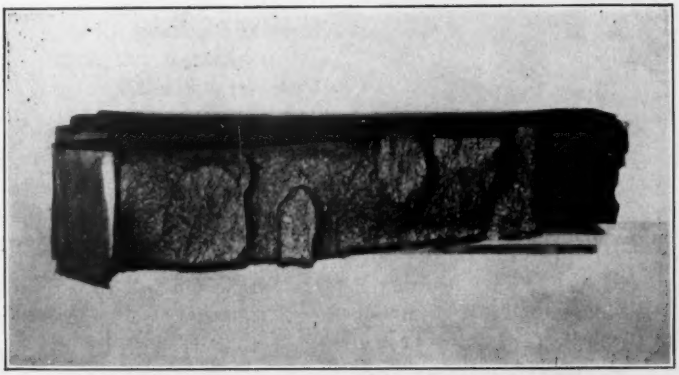
* These cracks are "flakes" in alloy steel, caused by too high cooling rates from the forging temperature. The cracks vary in size from the visible to the invisible. Determinations on the width and depth of various thermal cracks are being made and the results will be given in a supplementary report.



RECORD OF MAGNETIC POWDER INDICATIONS OF FLAKES (THERMAL CRACKS) IN A SLICE CUT FROM THE GEAR BODY OF A DEFECTIVE PINION FORGING.



RECORD OF MAGNETIC POWDER INDICATIONS OF FLAKES ON JOURNAL OF PINION.



SLICE FROM GEAR BODY SPLIT AT INDICATED CRACK TO EXPOSE
A SERIES OF FLAKES.

(B) Magnetizing fields

1. Circular magnetization
   (a) Continuous method
   (b) Residual method
   (c) Surge method
2. Bi-polar magnetization
   (a) Electromagnet

(C) Magnetic particle indicators or inspection mediums

1. Wet method
   (a) G-E Magnetite, suspended in kerosene, sprayed
   (b) Magnaflux paste, suspended in kerosene, sprayed
   (c) Wieco paste, suspended in kerosene, sprayed
   Note—1½ ounces of Magnetite or paste to one gallon of kerosene.
2. Dry method
   Magnaflux powder No. 1
   (a) Applied by bulb
   (b) Applied by Magnaflux power blower

Test Rotors.

The three different turbine rotors of alloy forging steel used in this series of tests are identified as follows:

Rotor No.	Maximum Diameter Inches	Minimum Diameter Inches	Photograph Print No.
1	19	3	596526
2	28½	4⅜	596527
3	44¼	5¼	597735

Tests were concentrated on different size thermal cracks located at different diameters on the rotors. In all cases the selected thermal cracks were outlined by prick-punch markings so that the area could be located when in the demagnetized condition.

Test Procedure.

The current leads were connected to the forging at the extreme ends of the governor journal and the coupling.

Before proceeding with each series of tests, the rotors were thoroughly demagnetized by passing 3000 amperes a-c through

the entire length of the rotor and gradually reducing the field of the alternator to zero current. The rotors were then checked for demagnetization by scotch tape recordings of the defect (not included with this report) to make sure no residual indications were present.

In making the a-c, d-c, and rectified d-c tests, the procedure followed was to apply a current of 200 amperes, record the magnetic particle pattern and then increase the current in steps depending upon the previous indications. At each step of the test, the current was maintained at a constant value for sufficient length of time to record the pattern. This is known as the continuous method when the magnetizing force is maintained while applying the magnetic particle indicators.

When making the surge tests, the magnetizing current was raised to 3000 amperes, held for 3 seconds, then reduced to 1200 amperes and held at this value while applying the magnetic particle indicators and recording the patterns.

The residual tests were made with increasing currents up to a maximum of 3000 amperes and recording the patterns after removing the magnetizing current.

The continuous and residual tests made with the storage batteries were limited to 1600 amperes because of the lack of current control.

In using the wet method, the indications were flushed with carbon tetrachloride applied by bulb and glass tube. After the surface had dried, scotch tape recordings were made of the indication. In the case of dry powder applied by bulb, the excess powder was blown off. Where the dry powder was applied by power blower, the low pressure air-jet, which is a feature of this blower, was used to remove the excess powder.

The procedure followed throughout these tests was the same as that ordinarily employed in magnetic particle testing. An effort was made to standardize the test procedure as far as possible but no attempt was made to secure well developed or filled-out patterns and each recording is representative of the actual indications under ordinary test conditions".

In describing the results of the tests several photographically recorded indication sets encompassing a wide variation of diameters were used. To illustrate the effect of increasing diameter, six of these are adjacently shown and the discussions follow:

Again to quote directly:

"Figures No. 1 and 1-A show a series of tests made on a large size thermal crack located on 3 inch diameter of the No. 1 journal. Because of the size and location of the crack, the amount of leakage flux produced revealed the defect very readily.

It will be observed that all indications were clearly brought out by the wet methods with the minimum current of 200 amperes.

The dry powder applied by bulb gave good indications with 200 amperes and the powder applied by blower gave faint indications up to 800 amperes except by the d-c method which revealed a good indication at 400 amperes.

The 4800 ampere-turn electromagnet gave a good indication with the wet method and an indistinct indication with the dry method.

Figures 7 and 7-A show a series of patterns on a large size thermal crack located on 11¼ inch diameter high pressure inner packing.

Wet method—At 400 amperes the a-c and d-c methods gave good indications whereas the rectified d-c, d-c residual and rectified d-c residual only gave faint indications. The d-c residual patterns improved at 560 amperes. All indications were clearly brought out at 800 amperes by the various methods.

Dry methods—At 560 amperes the bulb and power blower methods gave good indications with a-c and d-c, and fair indications with the d-c residual method. With a current of 800 amperes all indications were clearly brought out in the patterns.

Note: After completing the tests on the No. 2 rotor it was necessary to return the power blower. The tests on No. 3 rotor were therefore only made with dry powder using the bulb method.

Another series of photographs (not reproduced here) covers a series of patterns made on a comparatively long and fine thermal crack located on 26¼ inch diameter, on steam deflector wheel.

Wet methods—Some methods revealed only faint indications up to 800 amperes but at this value of current good indications were revealed.

Dry methods—Powder applied by the bulb gave faint indications up to 800 amperes and only fair indications at 1200 amperes. At 1600 amperes all of the indications were good.

Figures 9 and 9-A cover a series of patterns obtained on a thermal crack located on 28¼ inch diameter, on steam deflector wheel of rotor.

This fine thermal crack is on the vertical surface of the steam deflector wheel and is located on the largest diameter at which defects were found on the three rotors investigated.

No indications were obtained by any of the methods employed up to 1600 amperes.

D-c wet method—The wet method gave satisfactory indications at 1600 amperes by all methods including the electromagnet but not the electromagnet residual test.

A-c wet method—A faint trace of the thermal crack was obtained at 1600 amperes and only a fair indication was brought out at 2000 amperes. It was necessary to go to 2500 amperes to obtain an indication comparable with 1600 amperes d-c.

D-c dry method—Satisfactory indications were obtained with 1600 amperes by all methods except the rectified d-c residual test.

A-c dry method—No indications of the crack appeared until 2000 amperes was applied and then only a trace of the indication was obtained. It was necessary to increase the current to 2500 amperes to get a fair indication which, however, was not as good as the indication obtained with d-c by the dry powder method at 1600 amperes."

The following "Remarks" are quoted because of their general interest to the subject:

"The suspension properties of the pastes account for some of the extremely dark backgrounds found in certain patterns. When the tests were made with a-c, the forgings heated appreciably due to eddy currents. The heat quickly vaporized the kerosene allowing the magnetic particles to be distributed around the area sprayed and could not be flushed away with the carbon-tetrachloride which resulted in a dark background. This is also true in the case of some of the d-c patterns where the forgings became warm because of the high amperage and length of time required to make the test.

It should be mentioned that several of the tests were made on hot humid days and some of the dry powder tests, particularly those with rectified d-c currents gave indications which were not as good as might be anticipated. This may be accounted for if

MAGNETIC PARTICLE PATTERNS Fig. No. 1

Alloy Steel Forging. Max. Dia. 19"

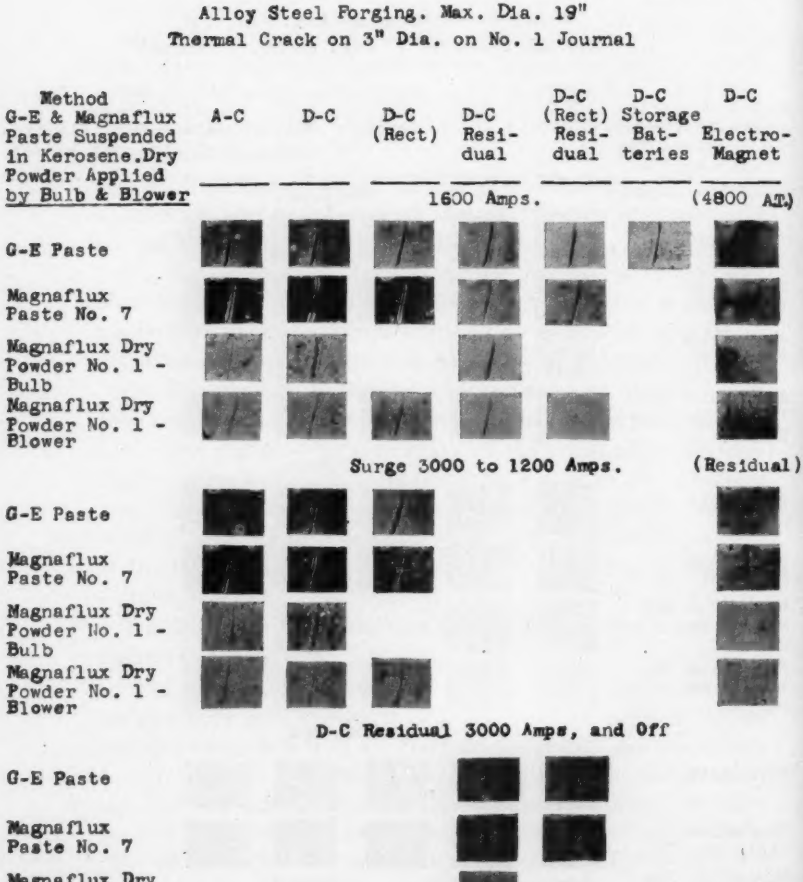
Thermal Crack on 3" Dia. on No. 1 Journal

Method G-E & Magnaflux Paste Suspended in Kerosene. Dry Powder Applied by Bulb & Blower	A-C	D-C	D-C (Rect)	D-C Resi-dual	D-C (Rect) Resi-dual	D-C Storage Bat-teries	D-C Electro-Magnet
			200 Amps.				
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							
			400 Amps.				
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							
			800 Amps.				
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							

MAGNETIC PARTICLE PATTERNS Fig. No. 1-A

Alloy Steel Forging. Max. Dia. 19"

Thermal Crack on 3" Dia. on No. 1 Journal


Method G-E & Magnaflux Paste Suspended in Kerosene. Dry Powder Applied by Bulb & Blower
A-C
D-C
D-C (Rect)
D-C Resi-dual
D-C (Rect) Resi-dual
D-C Storage Bat-teries
D-C Electro-Magnet
1600 Amps.
(4800 AT.)
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower
Surge 3000 to 1200 Amps.
(Residual)
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower
D-C Residual 3000 Amps, and Off
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower

MAGNETIC PARTICLE PATTERNS Fig. No. 7

Alloy Steel Forging. Max. Dia. 28 1/2"

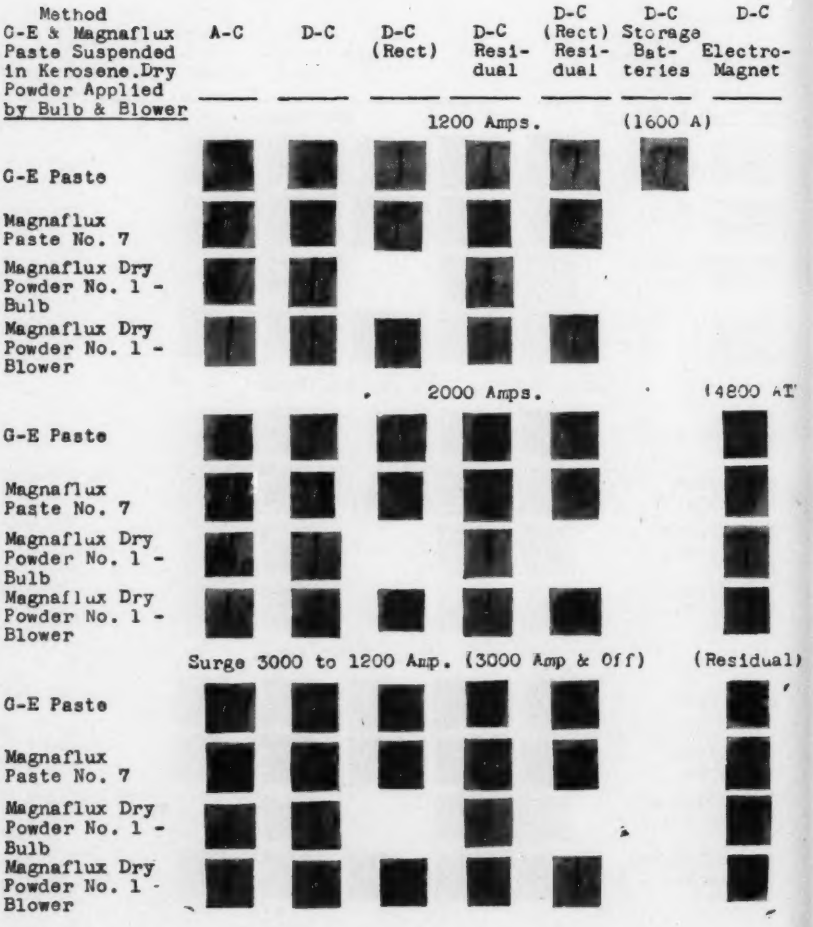
Thermal Crack on 11 1/4" Dia. High Pressure Inner Packing

Method G-E & Magnaflux Paste Suspended in Kerosene. Dry Powder Applied by Bulb & Blower	A-C	D-C	D-C (Rect)	D-C Resi-dual	D-C (Rect) Resi-dual	D-C Storage Bat-teries	D-C Electro-Magnet
				400 Amps.			
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							
				560 Amps.			
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							
				800 Amps.			
G-E Paste							
Magnaflux Paste No. 7							
Magnaflux Dry Powder No. 1 - Bulb							
Magnaflux Dry Powder No. 1 - Blower							

(+)

MAGNETIC PARTICLE PATTERNS Fig. No. 7-A

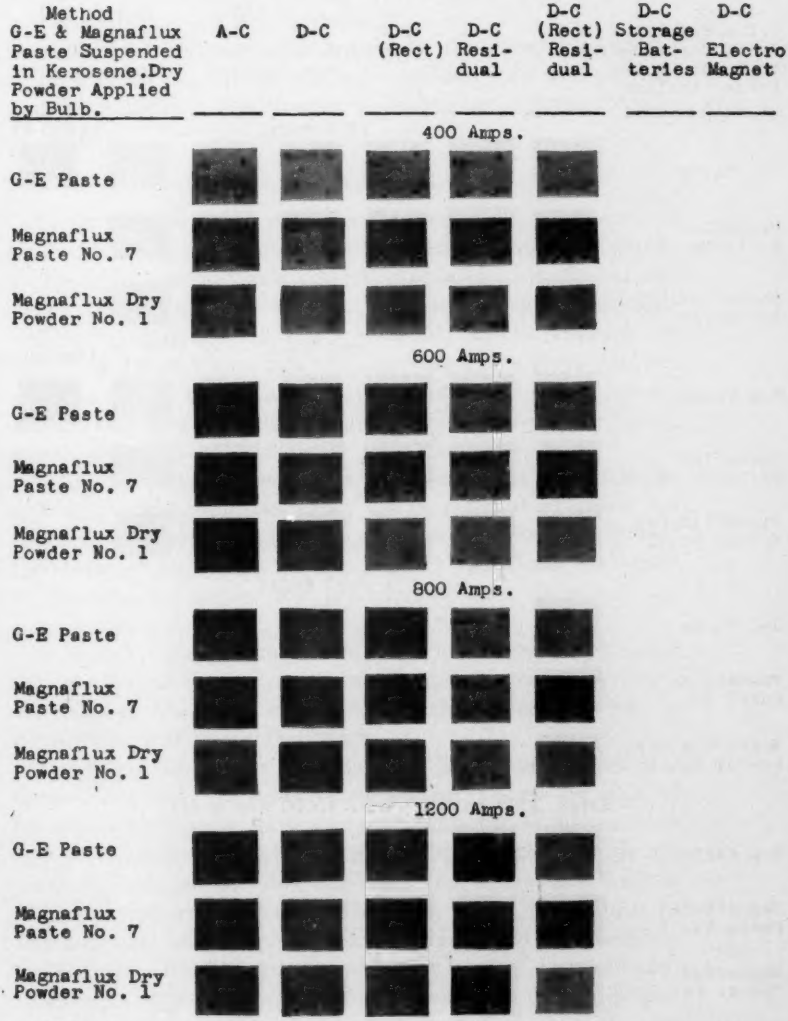
Alloy Steel Forging. Max. Dia. 28 1/2"
Thermal Crack on 11 1/4" Dia. High Pressure Inner Packing


Method
G-E & Magnaflux Paste Suspended in Kerosene. Dry Powder Applied by Bulb & Blower
A-C
D-C
D-C (Rect)
D-C Residual
D-C (Rect) Residual
D-C Storage Batteries
D-C Electro-Magnet
1200 Amps.
(1600 A)
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower
2000 Amps.
(4800 AT
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower
Surge 3000 to 1200 Amp. (3000 Amp & Off)
(Residual)
G-E Paste
Magnaflux Paste No. 7
Magnaflux Dry Powder No. 1 - Bulb
Magnaflux Dry Powder No. 1 - Blower

MAGNETIC PARTICLE PATTERNS

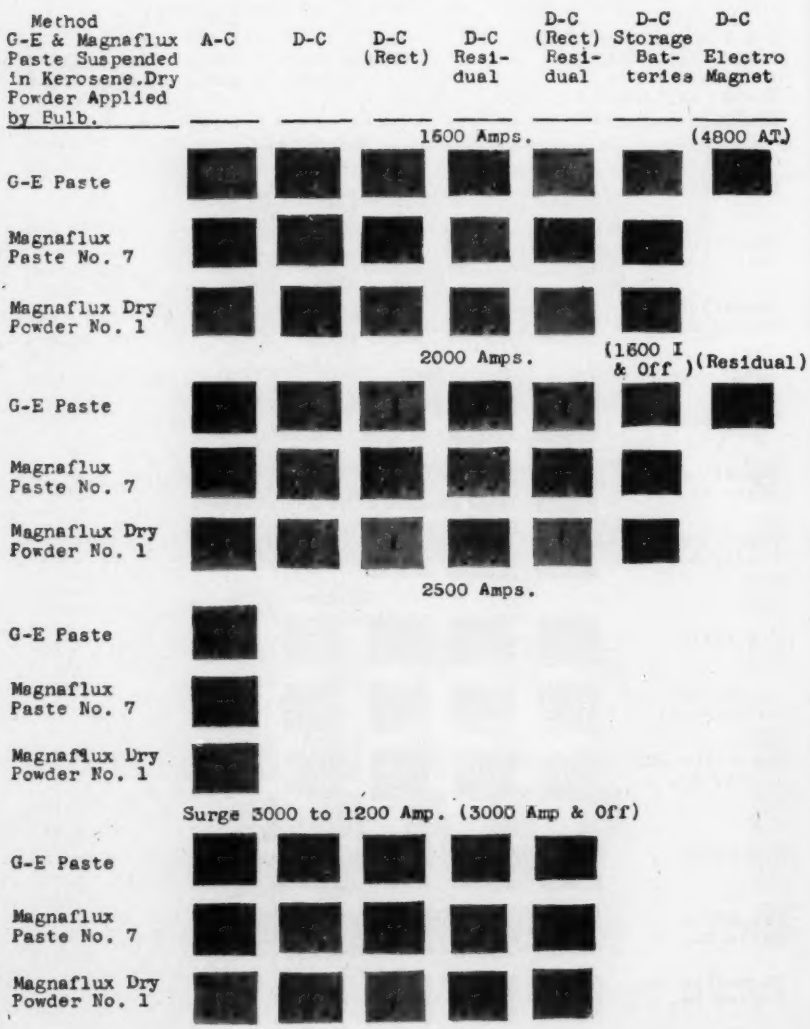
Fig. No. 9

Alloy Steel Forging. Max. Dia. 44 1/4"
Thermal Crack on 28 1/4" Dia. on Steam Deflector Wheel.



MAGNETIC PARTICLE PATTERNS Fig. No. 9-A

Alloy Steel Forging. Max. Dia. 44 1/4"
Thermal Crack on 28 1/4" Dia. on Steam Deflector Wheel.



the material is hygroscopic or its action is affected by atmospheric conditions.

When using the dry powder bulb on selected cracks where the location was known, the powder was applied until sufficient evidence of the crack was revealed.

In the case of the powder applied by the power blower, the distribution of the powder was more uniform than with the bulb and this would be a decided advantage when testing large forgings or castings."

Again, Proof of Method.

Earlier in this paper some mention was made of "proof of method". It is felt that assurance of dependable operation should be the first consideration in Magnetic Powder Inspection of any part. There is certainly no point to going through the motions only to miss some serious defect which may lead to failure of the part in service. Where repeated inspections of a given part are performed, it is often practical to determine the efficacy of the method employed by actually testing a comparative piece having known defects and by indicating those known defects.

However, in the inspection of large and more or less infrequently encountered parts it may not be practical to follow this practice. It therefore is necessary to depend upon experience of the personnel performing the inspection in determining the details of the employed method and procedure or upon competent outside advice.

It is the customer's prerogative through his inspector to insist that any inspection procedure actually and thoroughly performs the function for which it is designed, and he has the right to require proof of that performance.

It follows that he can require certain limitations on that procedure or approve the stated details thereof. These are some of the reasons for standardization or attempts to standardize methods and procedures. Much has been learned over the past decade about the relation of "flux densities" to "defect detection" in Magnetic Powder Inspection. However, rarely have studies of this important phase been recorded and published in a generally usable form. It is felt that the work done by the General Electric Company's engineers in correlating, in easily referred to graphs, the information obtained from their studies of thermal crack

indications by Magnetic Powder Inspection is broad enough in scope and detail to be of exceptional value to the art. It is the opinion of the authors based on considerable experience, that, though this work makes reference only to rotor forgings, the results obtained apply to other forged parts within the mass and diameter limitations indicated. In fact it should require little imagination or ingenuity to adjust the results to apply quite generally to this type of inspection of a large range of sizes, shapes and masses, of machinery parts. The following graphs and the matter related thereto are taken from this unpublished work.

Magnetic Flux Densities in Crack Detection.

(a) *D-C Continuous Method*

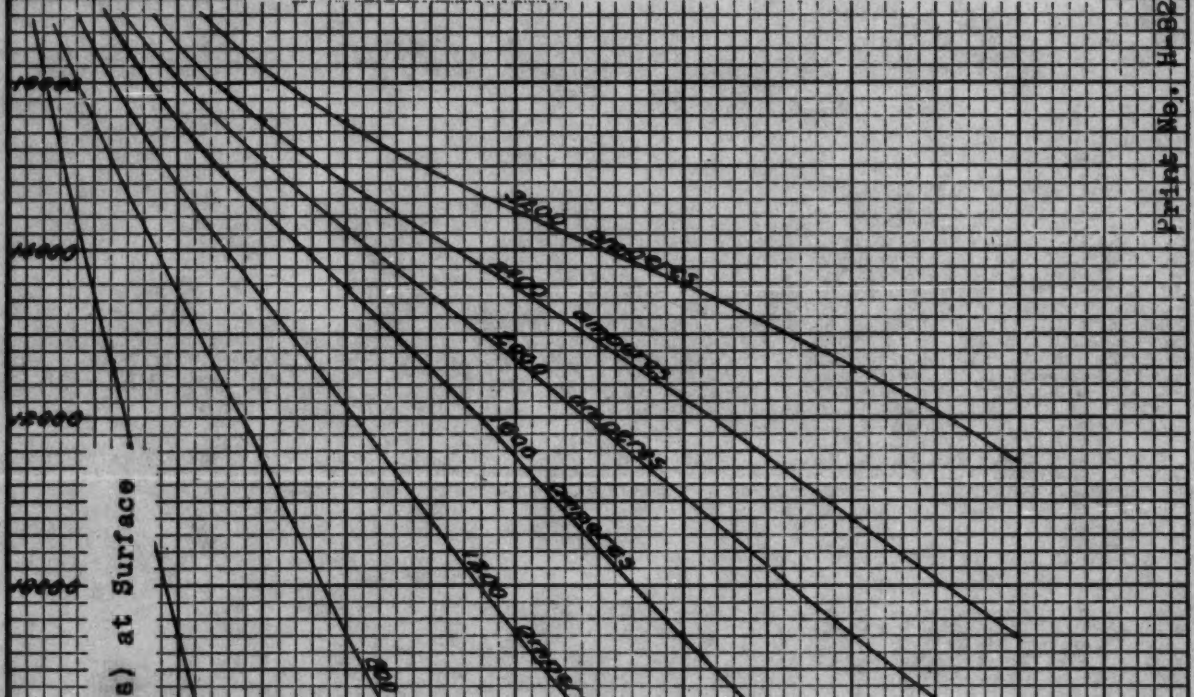
Prints No. H-8213127, -128, and -130 show curves obtained by calculations from test results, the relation between flux density, applied current, and diameter of rotor from which to estimate the current required for best results in the detection of surface defects in turbine generator rotor forgings.

Print No. H-8213128 shows typical d-c normal induction and permeability curves obtained by testing a ring specimen (3 cm. O.D. $\times$ 2.5 cm. I.D. $\times$ 0.5 cm.) cut from a rotor forging.

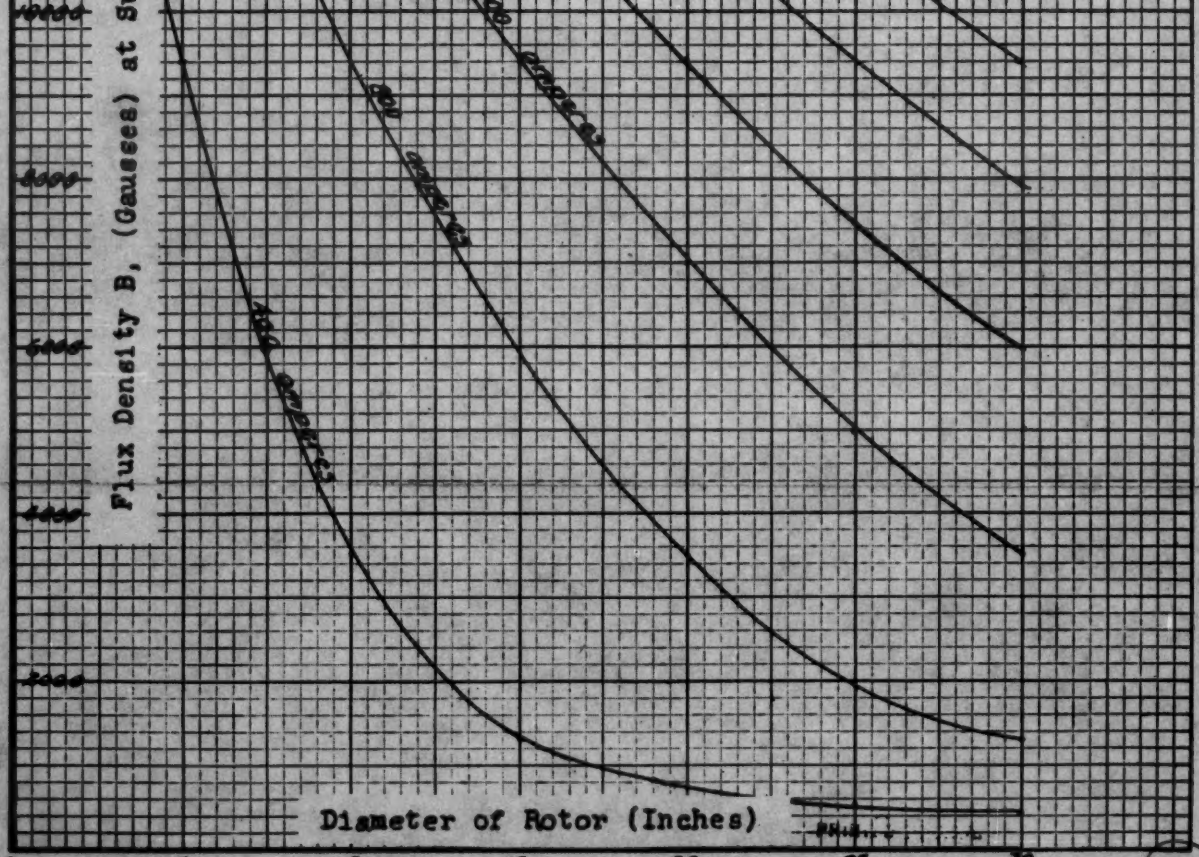
Print No. H-8213127 shows values of flux density, B, expected at the surface versus diameter of the rotor for different constant direct currents passing in the axial direction through the rotor. The densities shown (H-8213128) correspond on print H-8213127 to values of magnetizing force calculated from the formula $H = \frac{0.21}{r}$. This relation is applicable directly in this case since the magnetomotive force across a crack of ordinary width is very small compared to the total magnetomotive force around the circumference of the rotor.

According to these curves one might expect that for small diameters, the densities, B, would be comparatively independent of the current (above 800 amperes), but with increasing diameter, larger and larger currents would be required to produce similar flux densities. Over the ranges considered, the current required to maintain a given flux density, B, is approximately proportional to the diameter as shown on print No. H-8213130 and the ratio of this required current to the diameter increases with the flux

CALCULATED FLUX DENSITY, B (GAUSSES) AT SURFACE
VS. DIAMETER OF ROTOR, FOR DIFFERENT CONSTANT
DIRECT CURRENTS
REFERENCE--PRINT NO. H-8213128
General Engineering Laboratory
Date July 9, 1943 By Ping Yen
Revised Date August 28, '43 By Ping Yen

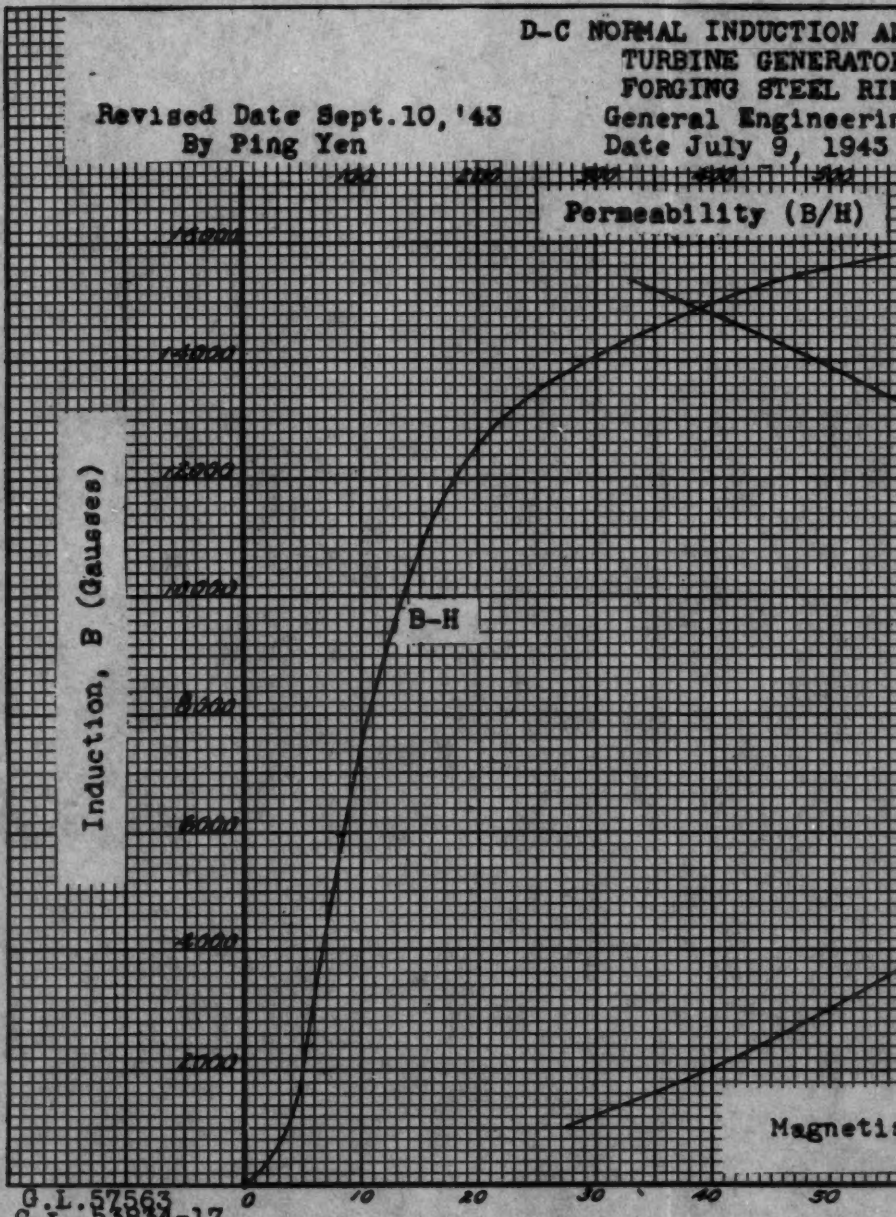


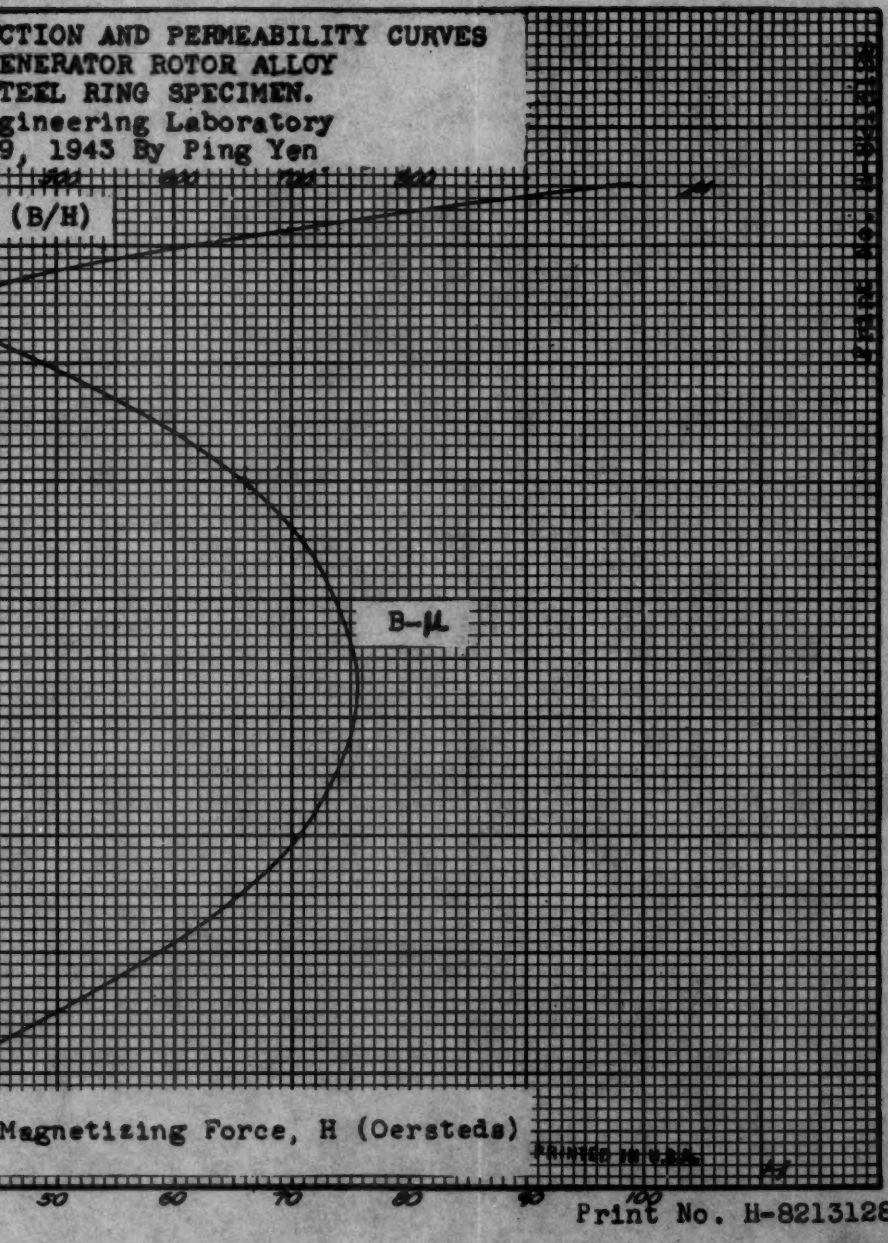
8213128-H Print No. Given Above



G.L.57563

Print No. H-8213127


D-C NORMAL INDUCTION A
TURBINE GENERATO
FORGING STEEL RI
Revised Date Sept.10,'43
By Ping Yen
General Engineeri
Date July 9, 1943
Permeability (B/H)
Induction, B (Gausses)
B-H
Magneti
0
10
20
30
40
50
G.L.57563
G.L. 53834-17

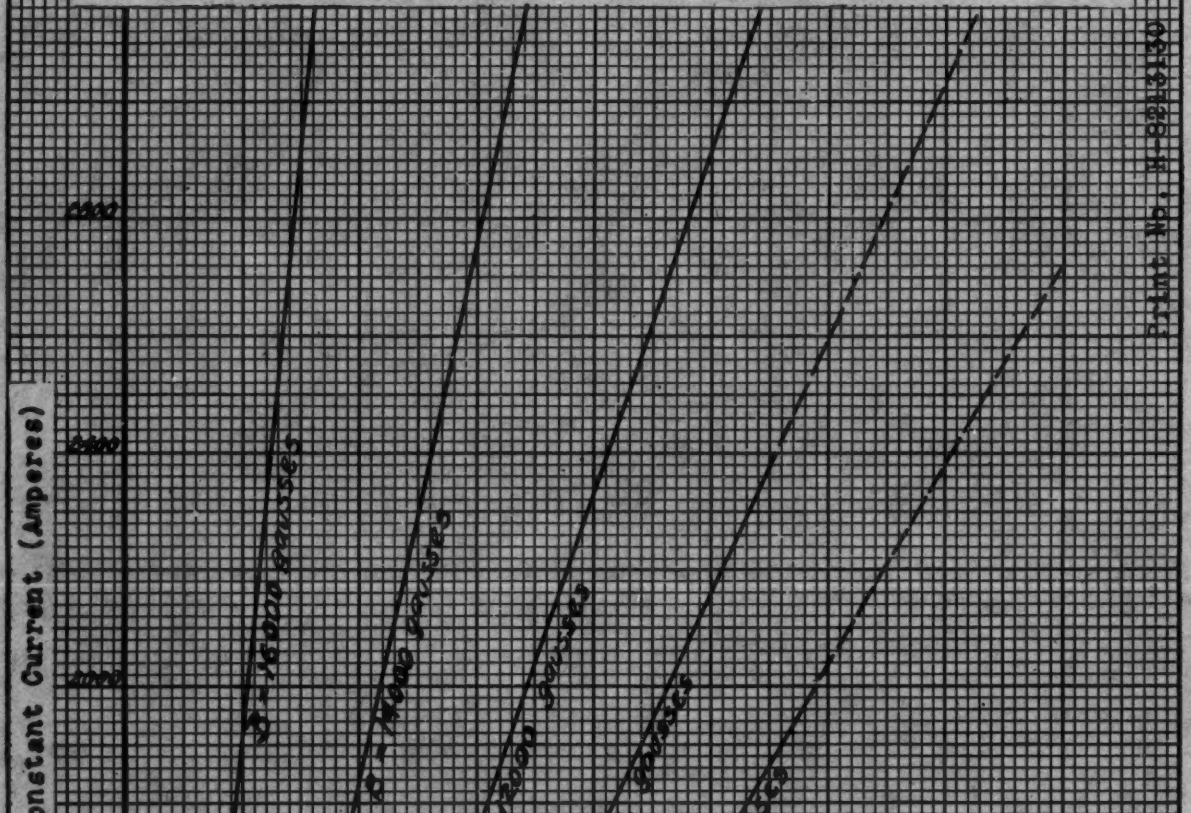


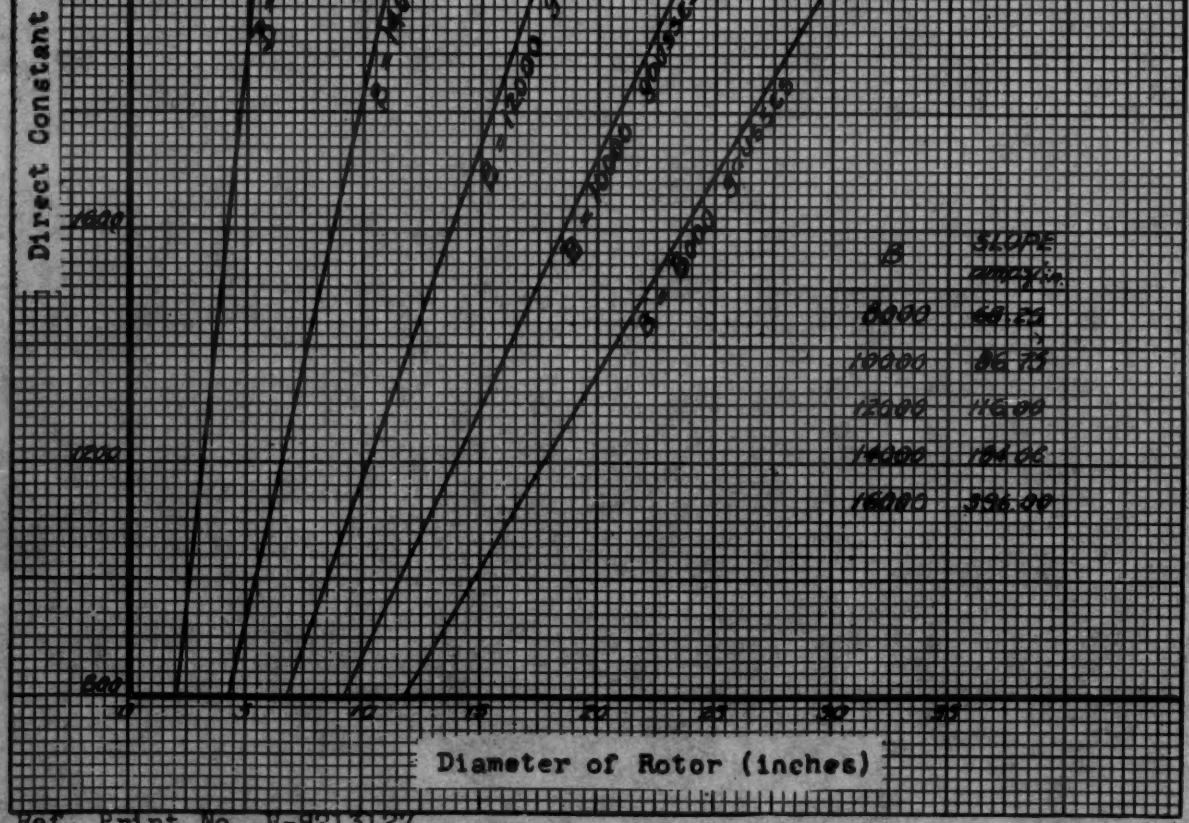
Print No. H-8213128

CONSTANT DIRECT CURRENT VS. DIAMETER OF ROTOR, FOR DIFFERENT CONSTANT FLUX DENSITY B (GAUSSES) AT SURFACE.

General Engineering Laboratory

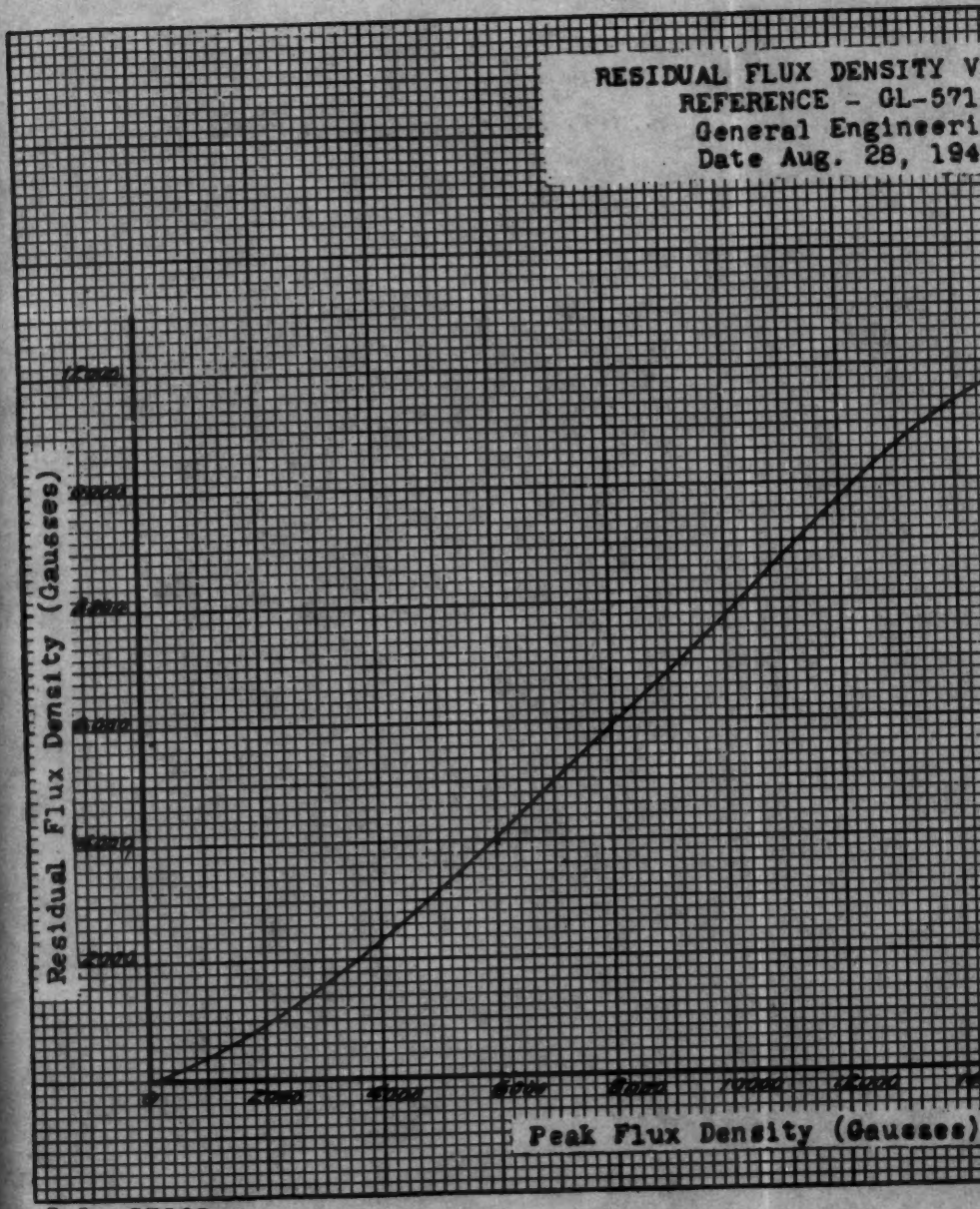
Date July 19, 1943 By Ping Yen



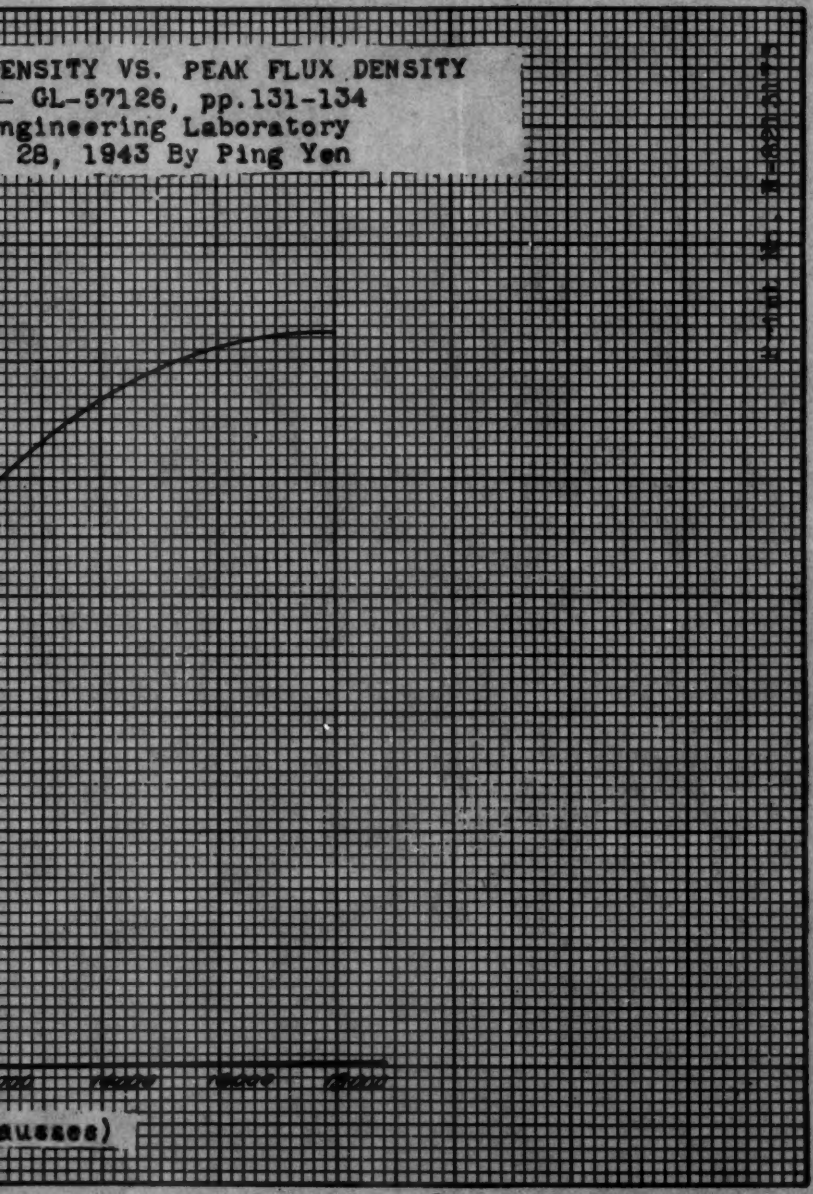


Ref. Print No. H-8213127
G.L. 57563

Print No. H-8213130


RESIDUAL FLUX DENSITY V
REFERENCE - GL-571
General Engineeri
Date Aug. 28, 194
Residual Flux Density (Gausses)
Peak Flux Density (Gausses)

G.L. 57563



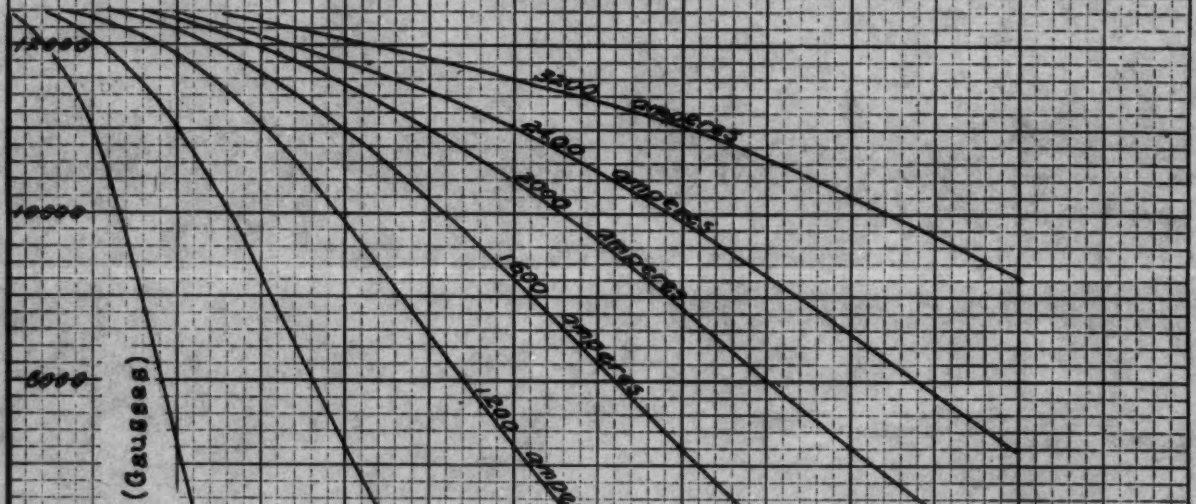
Print No. H-8213173

CALCULATED RESIDUAL FLUX DENSITY B_r (GAUSSES) AT SURFACE VS. DIAMETER OF ROTOR FOR DIFFERENT CONSTANT DIRECT CURRENTS

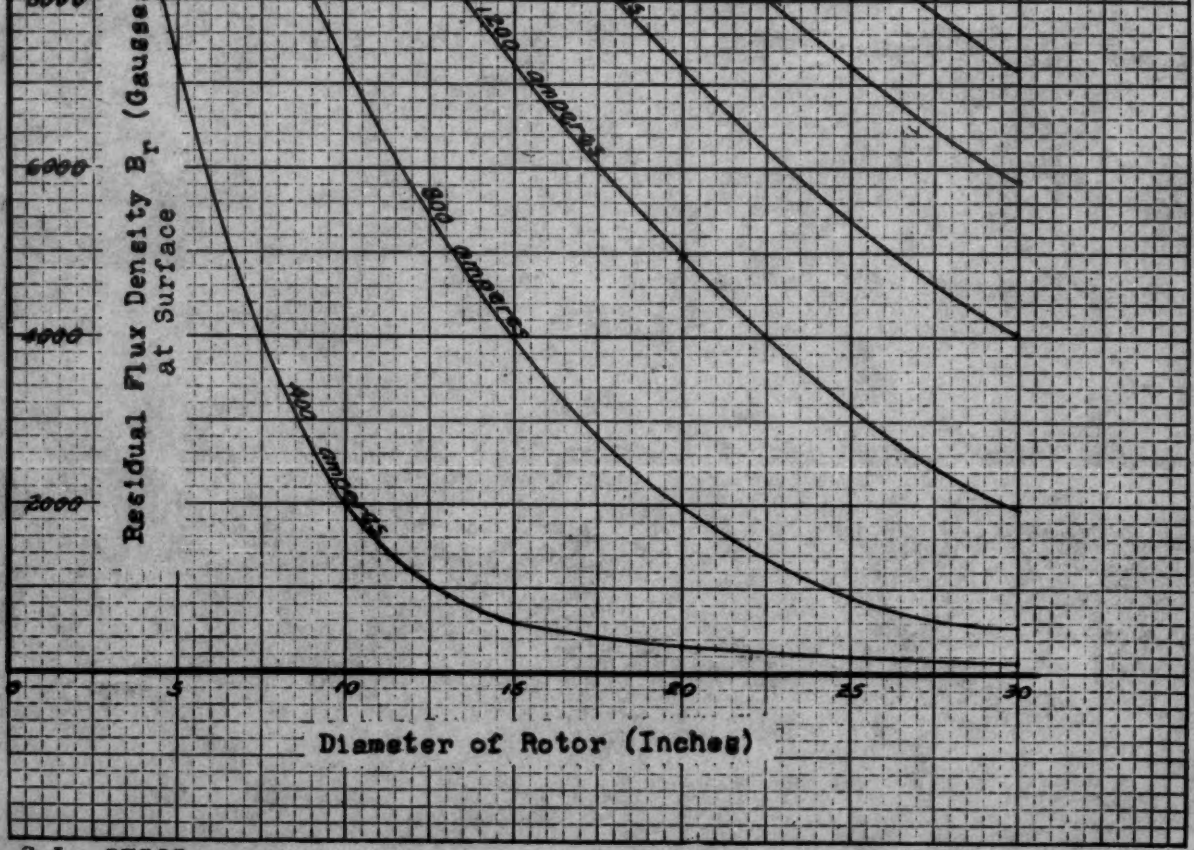
REFERENCE - PRINT NO. H-8213128

General Engineering Laboratory

Date Aug. 28, 1943 By Ping Yen



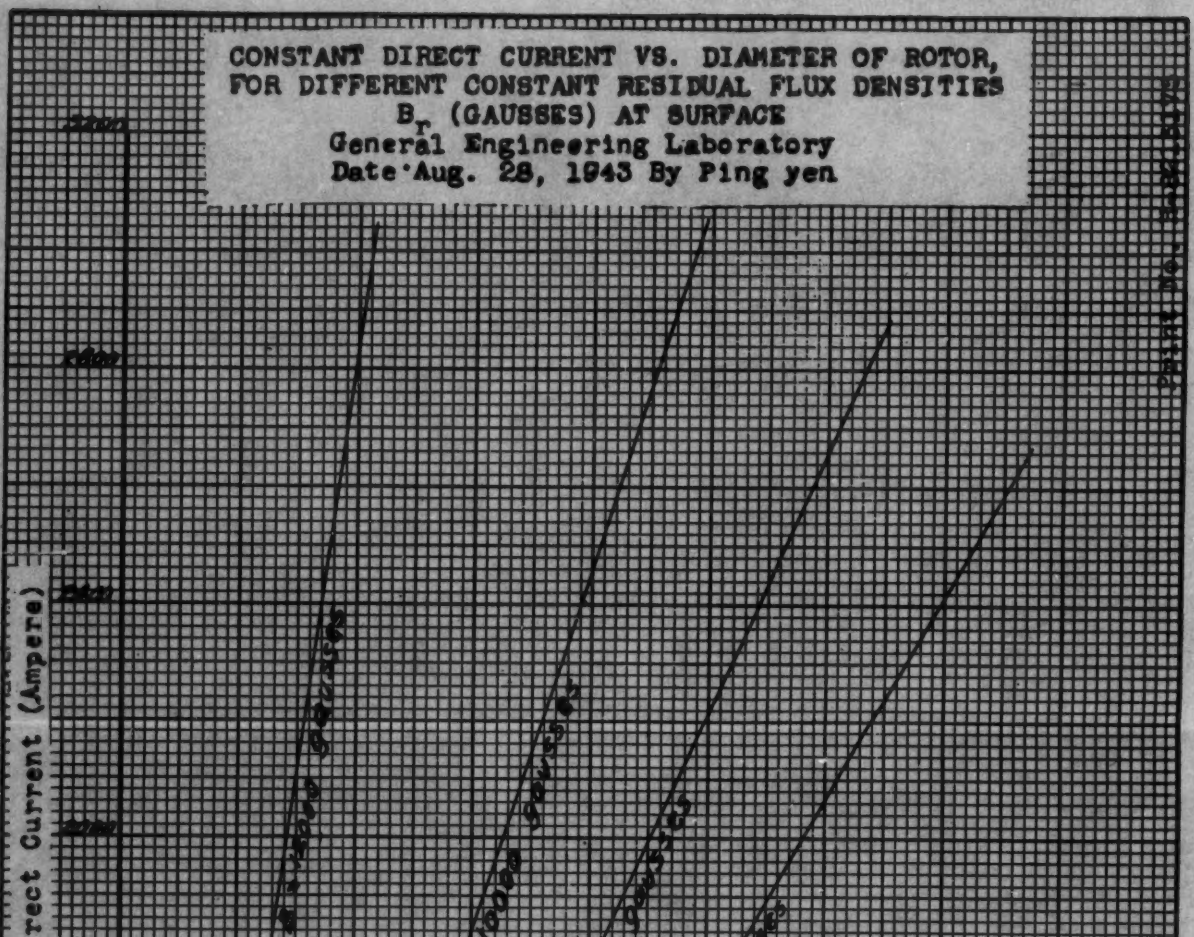
H-8213128 # on chart

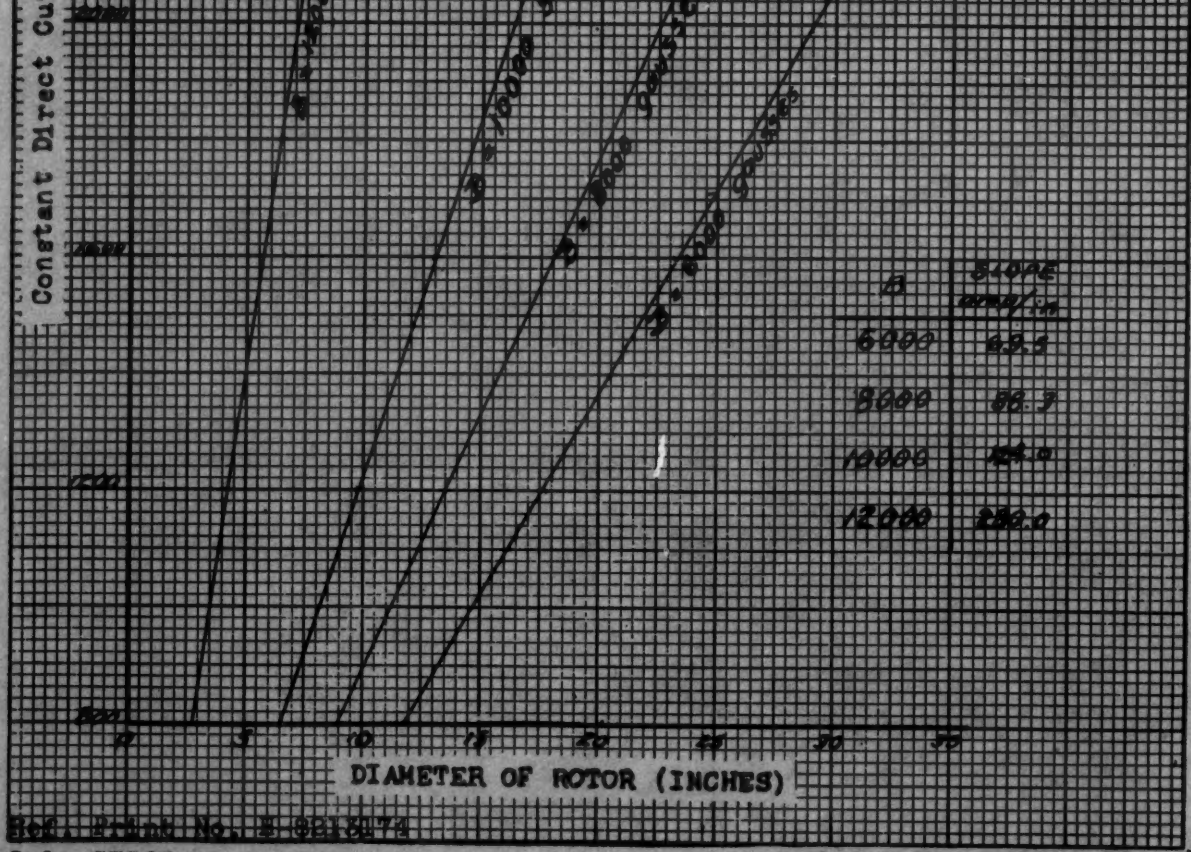


G.L. 57563

Print No. H-8213174

CONSTANT DIRECT CURRENT VS. DIAMETER OF ROTOR,
FOR DIFFERENT CONSTANT RESIDUAL FLUX DENSITIES
B_r (GAUSSES) AT SURFACE
General Engineering Laboratory
Date Aug. 28, 1943 By Ping yen





G.L. 57563

Print No. H-8213175

density, B. Thus, 68 amperes per inch diameter are required to maintain a flux density = 8000 gausses, but 400 amperes per inch diameter are required to maintain a flux density = 16000 gausses.

In actual tests made on rotors with 3 inch to 28¼ inch diameter, it was found that 1600 amperes d-c gave satisfactory indications and 2000 amperes was sufficient for best results. Print No. H-8213127 indicates that at the surface of a rotor 28¼ inch in diameter, 2000 amperes would produce a density of B-8500 gausses. This density corresponds on the curves to about 75 amperes per inch diameter. Therefore in a series of tests one would expect to find the most cracks with the least current if 75 amperes per inch diameter were used.

The density of B-8500 gausses is approximately 40 per cent of the saturation induction value of $B_s = 21500$ gausses for this class of material. It should also be noted in referring to print No. H-8213128 that this value of density occurs in the region of maximum permeability for the material.

(b) *Residual Method*

Prints No. H-8213173, -174 and -175 show curves obtained by calculations from test results, the relation between residual flux density, applied current, and diameter of rotor from which to estimate the current required for best results.

The method is similar to that given above, except that residual flux density is used instead of peak flux density.

Print No. H-8213174 shows the values of residual flux density, B_r, expected at the surface versus diameter of the rotor after being subjected to different direct currents passing in the axial direction through the rotor. These residual flux densities were obtained from calculated values of field strength H, from the normal induction curve (print No. H-8213128), and from the corresponding values of residual densities on print No. H-8213173.

The current required to obtain a given residual flux density is approximately proportional to the diameter as shown on print No. H-8213175 and the ratio of this required current to the diameter increases with flux density as in the tabulation on the print.

In actual residual tests on rotors, the peak currents sufficient to give good results, were found to be from 400 amperes in a 3 inch diameter section of the rotor to 2000 amperes in a 28¼ inch diameter section. This range corresponds to residual flux densities from $B_r = 10400$ to 6300 gausses and to current-diameter ratios from 71 to 130 amperes per inch. It may therefore be expected that in a series of tests one would find the most cracks with the least current if a value of 100 amperes per inch diameter were used. This value corresponds to a residual flux density of 9000 gausses or approximately 75 per cent of the maximum residual induction obtainable with this material."

The General Electric Company has recently developed a flux metering device which when applied to the surface of a magnetized part, gives a dial reading which, though arbitrary, varies with and bears a relation to the flux density in the part. The authors recently witnessed a demonstration of this device during inspection of a propulsion shaft forging. This forging was approximately 14 feet long, 10½ inch bore, 16¼ inch body diameter with end flange outer diameter about 28 to 30 inches. Magnetizing was performed by passing 400 amperes through six turns of cable, the ampere turns thus being 2400. The cable was wrapped loosely by passing it axially through the bore and returning on the under side of the forging. No attempt was made to center the turns of cable in the bore; they were simply allowed to lie in the bore. This non-centering of the cables with the bore causes variation in flux densities in the part. These variations were indicated by the above mentioned magnetic field gage by recording a series of readings taken on the surface at the forging. These readings taken during flow of current varied from 1.0 to 5.3.

With calibration of this magnetic field gage established, it appears to offer considerable promise as a quick means of scanning the various areas of large forgings of irregular cross section to determine that sufficient flux density exists to assure the desired indication of defects if present.

Precautions covering the use of high concentration of current applied directly to the part for purposes of magnetizing have been iterated and reiterated. Current is applied directly to the part either by—(a) mechanical connections which remain during the inspection, or (b) by the use of hand "prods" which are moved

from position to position along the surface. Mechanical connections should be so made that arcing, (which will cause burning) cannot take place. They should be rugged enough to maintain tightness of the contact during inspection. The electrical contacts must be of such area that local overheating will not take place. Copper braid backed with neoprene or other rubber substitute capable of resisting attack by the oil type wet method powder suspensoids has been found satisfactory. Hand prods are available with remote power control switches adjacent to the grips. Prods should be firmly held in contact with the surface until current is turned off, after which, removal can be made for repositioning.

It is, of course, highly desirable that current densities and duration, as well as combinations of these two, be maintained below the point at which objectionable heating takes place. Considering that current values may vary from 4000 amperes to perhaps 400 amperes for a range of inspections, here again, the technique of the operator, his equipment, his understanding of location and delineation of defects must be coordinated with properly detailed methods and instructions and criteria.

A good operator will know that a part must be properly prepared by thorough cleaning and drying for the dry method; that paint, dirt, loose scale, grease and such foreign matter must be removed to assure satisfactory results. He will know much about false and true indications and even about the qualitative and quantitative delineation of defects and their recording. He will maintain his equipment in efficient condition and guard against harm to the part under inspection.

It behooves the executive and the engineer not only to further the improvement of the good operator by continuing to simplify his problems with new aids as they become available but also to assure themselves that all operators are properly instructed, by making frequent checks of their work and by assuring that sound methods, instructions and criteria are prepared and understood, to the end that Magnetic Powder Inspection will continue to hold its place as a very important tool in non-destructive inspection of ferrous parts.

JOINT ARMY-NAVY STANDARDIZATION IN THE ELECTRICAL FIELD.

MR. JESSE B. LUNSFORD.*

PART I—INSTRUMENTS.

GETTING TOGETHER.

Much has been said recently about the desirability of the Army's and the Navy's "getting together". No reference is intended here to military strategy and tactics, but rather to such "home-front" activities as are normal to and surround the two largest of our executive departments in Washington; both of which are dedicated to the same end and both of which have large "administrative, professional and scientific" services handling many problems of common interest. With each of the two organizations so mightily expanded for the war effort there is every opportunity for some one, some where, to get out of line at some time; and make no mistake about it, they always have and no doubt always will because individualism is rampant in America. The engineer or scientist or administrator is not less individually minded than the average of the general population, but rather more so, and this makes for national progress.

If, therefore, our people do not always seem to live and work together in that degree of harmony we should like to see, let us not be too pessimistic about it. Let us remember that while "one swallow does not make a summer" any more in government than it does in business or in the home, "one frost does not make a winter," either. Let us, therefore, refrain from any too broad generalizations in matters involving such hordes of people and such diversity of actions, on the basis of too few data. Neither should the subject be dismissed from mind; rather let us consider that the failure of men to "get together" at times may be due to honest differences of opinion, and tackle the problem on that basis. Thomas Jefferson once said "differences of opinion lead to inquiry—and inquiry leads to truth".

*Bureau of Ships.

The author has watched one such "inquiry" carried through for a period of years and he believes that a review of it at this time and in the foregoing connection, might be of general interest far beyond the technical subject itself. Such ideas as Mr. Jefferson's quoted above may be likened to "acorns" which, if planted on fertile soil, grow into "oaks" in time. Having watched several rather nice sized oaks grow from small acorns buried years ago, it is the specific purpose of the author in this discussion to follow this thought through certain engineering phases for the ideas which might be engendered thereby, and it might even be that a few more "acorns", dropped at this time could land on fertile ground and grow. The immediate story covers *Instruments*, but it is to be told backwards in order to illustrate some of the ideas better. For the acorns the author has in mind do not cover materiel—they cover "ideas" believed to be basic to our democratic system and thus applicable to many things technical or otherwise.

Competitive Doubts.

First, however, let us try to see ourselves as others see us; maybe there is a lesson. The very fact that political opponents, radio news commentators, the press and maybe the public generally raise questions of interdepartmental governmental coordination, must mean that there is some "fire" somewhere; otherwise why the "smoke"? All peoples, being themselves and individually imperfect, are prone to believe that when large aggregations of individuals are housed together, the "organization" will result in some errors. As a democracy they should be encouraged to look constantly for errors lest they grow out of control; the people will no doubt always have enough exercise in this direction to keep themselves "in good training". Our natural resiliency is such, however, that this means a healthy condition and generally these things take care of themselves. So why deny the possibility of such actions? Why not help "look for them"? Such a search may give us more ideas to work upon.

Even the Congress must have its doubts at times. From the tone of certain bills which have been offered at one time or another it would appear that Congress might have in mind some definite means of assuring the closer collaboration of Army and Navy in the administrative, technical and scientific fields as

distinguished from the purely military. From all of this one might very easily get the impression that the Army and the Navy are "foreign" to each other.

It is even possible that some of the general public's impression of intense rivalry, not to say "war" between the Armed Services, may spring in part at least from the innocent jibes which we as a people are always flinging at the fellow "on the other side of the fence", any fence. The fun we poke at the "other fellow" in peace time, the way we try to "out do" him or to "win over him" means just one thing; it means that there are *two or more* teams; and the objective of any team is to play *against* other teams. We never operate together or in unison unless we are on the *same team*, just one team. One can never have *two* teams really working together, for the simple reason that the instant they both start playing with each other instead of against each other, all the normal party or team lines disappear and everything becomes as *one* team. Now if we are ever going to learn to play together we must stop even thinking or acting as if there were any such thing as the "other fellow". We cannot say "him" and think or act in terms of "we".

No organization or even the lack of one can make a "we" team. Neither legislation nor administrative order can produce a single "we" team. Neither can one be invented or just willed in that way. Teams can only be *built* over a period of *time* by a *leader* with a *purpose* to which all can *subscribe* and operate according to a *plan* which has been *developed* to the point of *workability*. So if anyone is waiting for a law to be passed or a new type of organization to produce such a team he is merely marking time. A "we" affair starts with an idea and has to "grow". It is a "seed", not a law nor an order; it cannot be *made*, it has to be "sown" on good ground, That is basic.

Normal Differences in Viewpoint.

Undoubtedly there are major differences in standards, in methods, in procedures and in the manner of thinking as between the two services. To fail to recognize these would be to shut one's eyes to the true situation. As a matter of fact, however, the differences in actions and in the manner of thinking, as between the several sections or groups within one bureau or branch of either of the two Armed Services is probably as great or maybe even greater than that between the two Armed Services

taken as a whole. In short, these differences are due to the variability of people themselves rather than to any particular organization or uniform. If we are to live with the type of democracy which is the sole purpose of the two Armed Services to fight for, then we must not "pooh-pooh" these differences as such, but rather make use of them as a system of checks and balances, i.e., to make sure there is enough loyal opposition to keep things headed in the right direction.

To call too much attention to these differences, on the other hand, so that the *differences* rather than the *similarities* are emphasized, might likewise give an erroneous impression. Furthermore, if the "differences" only, are pointed out too often and too strongly, then the effect might be actually to aggravate such differences as are normally expected and possibly to produce differences where none previously existed. To deny differences is to live in a false world; to emphasize them too greatly is to create one.

It is the purpose of this article, and of others which may succeed it to point out how certain groups in both the Armed Services and also in Industry, working together and trying hard to understand and to learn from each other, have already come up with some agreements which are of mutual aid in the present crisis; and these actions may help to establish successful patterns on an even broader scale for the future. For that reason the discussion concerns itself more with the means and mechanisms, as well as the historical aspects of this particular project, rather than the engineering details of electrical measuring instruments as such.

The story of "joint standards" for electrical measuring instruments is not finished with what has been achieved to date; what has been accomplished as yet is but a mere beginning. It is true that we have agreed upon a system of joint standards for electrical instruments, and that so far as American industry is concerned, all branches of the Army and the Navy are as one; but this is not the ending of the story; it is just a good start. At this point we have reached a stage where our rate of progress can be stepped up still further; a good place for a look backward to see where we came from and a time to consider how best to go forward; not on instruments alone but in many other matters of common interest.

This particular story does not start with now, last year, or

even at the beginning of this war. And it is not the beginning of any specific plan or scheme of the Army and the Navy to "get together". Things of consequence seldom start that way. Oaks always start out as acorns, buried years before, and there are many vicissitudes in the life of any oak and many more years may elapse between the "sprouting" of an acorn and the finishing of a highly polished oaken end product. This particular acorn was buried as long ago as 1924; but let's start walking backward from this year of 1944; let's walk backward through twenty years, as this may show the pattern more clearly.

JAN STANDARDS.

In this year 1944 the joint standardization program, insofar as it relates to electrical measuring instruments is bounded by the following standards and proposed standards:

JAN-I-6

Instruments, Electrical Measuring, Indicating; Basic Voltmeters and Ammeters.

Signal Corps	BuShips
Tentative Spec.	Ad Interim Spec.
71-4939	17-I-12(INT)

JAN-S-61

Shunts, External Ammeter (Lightweight Type)

Signal Corps	BuShips
Tentative Spec.	Ad Interim Spec.
71-4923	*17-S-31(INT)

JAN-R-29

Resistors, External, Meter (High Voltage Ferrule Terminal Type)

Signal Corps	BuShips
Tentative Spec.	Ad Interim Spec.
71-4922	*17-R-16(INT)

JAN-S-44

Shock-Testing-Mechanism for Electrical-Indicating Instruments

Army Number	Navy Number
72-82	17S29

JAN-T-60

Thermocouple Converter, External

Signal Corps	BuShips
Tentative Spec.	Ad Interim Spec.
71-4921	*17-T-29(INT)

This series of joint standards on instruments is the result of many conferences, much discussion, a lot of laboratory testing on all sides and much "getting acquainted with the other fellow". Of all the factors mentioned, the last one named is the most consequential: Credit goes to several organizations and to many individuals; and just by way of illustrating how much of a "we" venture it is, an attempt will be made hereinafter to name the principal contributors. But first let us exhibit some of the present fruits of such collaboration.

POOLING OF TECHNICAL INFORMATION.

Complete collection, classification, dissemination and a full understanding of all the technical information and data are not only prerequisite to an initial agreement upon standards; they are even more vital to the continuance of such collaboration. To that end the following exchanges did take place, are taking place and will take place:

Service experience and ideas.
Test data, methods of testing, etc.
Correspondence with manufacturers and others.
Conferences between various branches of the Armed Services and with industry.

The pooling of service experience and ideas are of even greater significance to the future than the present because it may form the basis for further research and development; it may mean far more rapid and effective developments in line with service needs because of the combined talents exerted, and it will avoid any possible duplication of effort or of diverging efforts. As several branches of the Armed Services already have, individually, great quantities of technical data, their pooling of it represents by far the greatest single array of technical information on some of these subjects to be found anywhere. Every-

*These specifications were all, at one time, a part of 17-I-12. Navy Specification 17-I-12 was split up in order to fit into Army practices, since different branches of the Army have cognizance over different types and sizes of instruments.

MEETINGS—ELECTRICAL INDICATING INSTRUMENTS

	Date	Office	NDBS	SC	WPB	IND.	ASA	OP & M	AERO. BD.	OPA	Other	Total
1.	25 Jun. 42	ASA	4	2	12	9				1	*3	31
2.	23 Jul. 42	ASA	2	7	1	5	3		1			19
3.	14 Oct. 42	ASA	3	7	2	15	2					29
4.	27 Nov. 42	ASA	3	6	1	7	2					19
5.	17 Dec. 42	ASA	2	5	1	2	2					12
6.	24 Apr. 43	RB, N. J.	2	7								9
7.	30 Jun. 43	W, D. C.	7	5		4	2		1			19
8.	9 Aug. 43	ASA	1	5		5	2				†1	14
9.	23 Nov. 43	ASA	2	1	2	14	3	1			‡3	26
10.	1 Dec. 43	W, D. C.	1	1	7			2			§3	14
11.	2 Dec. 43	W, D. C.			1	7						8
		Total	27	46	27	68	16	3	2	1	10	200

Note: SC Column includes all activities in the Signal Corps, U. S. Army.

*A-N Munitions Bd.—2, Ordnance Priorities—1.
†AAF Materiel Command, Wright Fld., Ohio—1.
‡Radiation Lab., MIT—1, Dept. Munitions & Supply—Canada—1, ASF, Office of Chief of Ord.—1.
§Aircraft Resources Control Office—1, ASF—1, BuAer—1.

thing the Navy has done, is doing and proposes to do, is turned over to the Army; the Army is reciprocating in kind.

Through individual correspondence, discussions, contacts, etc. that part of the electrical industry having to do with instruments is likewise kept informed; in fact Industry is the third partner and not only is it kept informed as to what goes on between the services, but it is encouraged to take part in it. This in one field where Industry has always played an important hand. Conferences, when necessary, are held at the places and times deemed likely to promote the greatest overall good with a minimum expenditure of time and effort. The tabulation on page 194 of the more important, formal conferences within one short period (period of greatest recent activity) is intended to give some idea of the cross-section of interests involved:

It should be borne in mind that the above does not by any means cover all the conferences which have been held; many conferences were held before that period and some have been held since, with more in prospect, because the only way to keep together in a moving field is to "confer" often. But the above tabulation does show a "cross section", and that is the purpose of this tabulation.

To show that this project has been truly representative of the technical leadership in the U. S. Government and Industry, here are a few of the names of those who have taken part in one or more formal conferences:

BUREAU OF SHIPS, NAVY DEPARTMENT.

Albright, A. R. G.
Bailey, W. H.
Blaylock, L. B., Cdr.
Boymel, B. R.
Burgess, R. O.
Chamberlain, A. B., Cdr.
DeMoss, G. N.
Ford, M. A.
Forsyth, E. C., Capt.
Friebus, R. T.
Fuller, W. R., Lt. Cdr.
Gantt, F. M.
Haas, P. G., Cdr.
Hall, J. N.
Kaufmann, J. S., Lt.
Latrobe, W. C., Capt.
Lion, P. M., Lt. Cdr.
Lunsford, J. B.
Seaman, E. F.
Wagner, W. C., Cdr.
Woodside, A. G., Lt.

Office of Procurement and Material.

Crawford, R. B., Lt. Cdr.
Geiges, K. S., Lt. (jg)
DeGroff, R. L., Lt. Cdr.
Haydock, J. G., Jr., Lt. Cdr.

Joint Aeronautical Board (Army and Navy).

Groen, W., Lt. (jg)
McCabe, H. V., Capt.
Spano, B. S., Capt.

Signal Corps, U. S. Army.

Bishoff, Theodore, Maj., OCSigO
Bunting, T. R., SCASS
Carter, R. N., Capt., SCASS
Castellini, N. R., SCGSS
Cunningham, R. F., Maj., OCSigO
DeVito, D. J., SCSA
Lutton, L. E.
Edwards, W. H., Maj., SCGDL
Framme, R. J., SCASS
Gantt, J. S., Lt., SCGSS
Garson, A. J., Maj., SCSA
Glad, P. S.
Held, C. J., SCASS
Larsen, G., SCRL
Larson, G. R., SCRL
Lichtenberger, W. H., Capt., SCGSS
Meltvedt, Henry
Miller, H., SCASS
Okun, A., SCASS
Priebe, F. K., SCGDL
Rowe, D. D., SCSA
Smith, N. R., OCSigO
Steffen, G. W., SCGSS
Tindall, H. D., Lt., SCGDL
Wyly, J. J., Maj., SCSA
Zaretsky, Sol, OCSigO

American Standards Association.

Ainsworth, Cyril
Chertok, S. L.
Kosofsky, J.
McNair, J. W.
Westman, H. P.
Wilsey, H. R.

War Production Board.

Batman, C. H.
Bell, O. M.
Burmaster, C. J.
Cahn, B. D.
Clark, J. A.
Crane, E. R.
Crosby, Charles R.
Fritze, J. R.
Gearhart, W. V.
Hodgson, Millard
Moody, T. J.
Myers, R. K.
Randall, L. M., Jr.
Rockwell, H. P.
Saunders, Charles L.
Shepard, R. B.
Simpson, Ray R.
Wolf, S. K.
Worden, L. R.

Other Government Agencies.

Bridge, M. R., MIT
Des Brisay, A. W. Y., Lt., Col., Dept. Munitions & Supply—Canada
Ertell, M. W., OPA
Hemenway, K. H., Aircraft Resources Control Office
MacFarland, G. F., ASF
Silsbee, F. B., U. S. National Bureau of Standards
Tucker, J. P., Capt., ASF

Electrical Instrument Industry.

Angus, D. J., Esterline-Angus Co.
Austin, C. S., Lewis Engr. Co.
Beede, F., Beede Elec. Instr. Co.
Bobier, F. C., DeJur-Amsco Corp.
Brogger, I. W., DeJur-Amsco Corp.
Carbonara, V. E., Square D. Co.
Daschke, A. W., Bell Telephone Co.
Downing, W. C., Jr., Sangamo Elec. Co.
Egert, S. S., DeJur-Amsco Corp.
Geer, C. D., Thos. A. Edison, Inc.
Gerstenberger, H. L., Weston Elec. Co.
Goodwin, W. N., Jr., Weston Elec. Co.
Heggy, J. M., Westinghouse Corp.
Hickok, R. D., Hickok Elec. Instr. Co.
Howe, W. F., Gen. Elec. Co.
Isaacs, R. H. Bendix Aviation Corp.
Kent, H. E., Edison Elec. Institute
Kinnard, I. F., Gen. Elec. Co.
Kuscher, J. J., DeJur-Amsco Corp.
Lamb, F. X., Sangamo Elec. Co.
Lingel, F. J., Triplett Elec. Instr. Co.
Loveless, C. A., Sangamo Elec. Co.
MacDonald, D. H., DeJur-Amsco Corp.
Manypenny, J. M., Bristol Co.
Master, C. B., Gruen Watch Co.
Miller, J. H., Weston Elec. Co.
Olesen, H. D., Weston Elec. Co.
Pattee, Lloyd, O. B. McClintock Co.
Rutter, A. R., Westinghouse Corp.
Simpson, Ray R., Simpson Elec. Co.
Smith, R. M., Roller-Smith Co.
Sparkes, H. P., Westinghouse Corp.
Swoish, W. R., Roller-Smith Co.
Triplett, R. L., Triplett Elec. Instr. Co.
Vaughen, F. G., Gen. Elec. Co.
Wehrle, E. J., Gen. Elec. Co.
Whipple, R. R., Western Elec. Co.
Whittenton, J. M., Gen. Elec. Co.
Williams, A. T., Weston Elec. Co.
Young, D. A., Westinghouse Corp.

The above list may not do justice to many who served informally, or who did more than their share of the work, but at least it is enough to show that this project was not a "one-man' affair. In the case of test reports of manufacturers' instruments it has long been the practice of the Bureau of Ships to furnish each exhibitor full information on the test data obtained in the case of his particular instruments. In order, however, that both the Army and the Navy might be entirely familiar with the data obtained by each other, it was earlier arranged to have the Navy furnish all its data collected between 1924 and 1942 to the Signal Corps; this was a rather voluminous exchange of technical data. The Signal Corps likewise reciprocated by a similar exchange with the Navy, but the Signal Corps data was not as voluminous as the Navy's. At frequent meetings held later between the several branches of the two Armed Services there was mutual discussion of this data and of all the specification requirements to which they related.

Pooling of Laboratory Facilities.

The necessity for conducting many new tests, re-tests and investigations prompted by the inauguration of these joint standards has required the full use of the instrument testing facilities of the Material Laboratory, Navy Yard, New York and of the Ft. Monmouth Signal Laboratory, Ft. Monmouth, N. J. Aside from the necessity of accomplishing all this testing within a reasonable time there is the further advantage of not having all one's eggs in one basket; if something happens to one laboratory to interfere with the work being done there it would still leave the other one in a position to relieve it immediately. This requires, of course, that the test methods be very carefully worked out both to simulate actual service conditions and to assure reproducability; and that the laboratorians in both laboratories concerned with this work be acquainted with each other and with all details of the tests being made at each laboratory.

In general, the present division of work load as between the Army and the Navy in the laboratory testing of instruments is about as follows (subject to such changes as may at times be necessary to meet work load conditions, etc.):

2½ inch sizes—90 per cent of instruments tested at the Ft. Monmouth Signal Laboratory, Ft. Monmouth,

N. J. The remaining 10 per cent being tested at the Material Laboratory, Navy Yard, New York.

3½ inch sizes—90 per cent of instruments tested at the Material Laboratory, Navy Yard, New York. The remaining 10 per cent being tested at the Ft. Monmouth Signal Laboratory, Ft. Monmouth, N. J.

4½ inch sizes
5½ inch sizes
6 inch sizes
7½ inch sizes
Miscellaneous
Special types

All instruments are, at present, being tested at the Material Laboratory, Navy Yard, New York.

The 10 per cent cross-exchange of testing on the 2½ inch and 3½ inch sizes indicated above is intended to serve as a means of checking the results of one laboratory against the other, to assure that they remain "in step" with each other at all times. This insures that an exhibitor will get exactly the same answer no matter where his instruments are tested. It is likewise the intent that the testing methods, equipment, etc. be so clearly defined that any outside industrial laboratory with proper facilities and trained personnel will get the same results and reach the same conclusions. If the Industry can get the same answers in their own laboratories that we do in ours, they have to come along with us. There is nothing for any one to argue about.

The number of complete "qualification" tests which have been conducted in government laboratories on types and brands of electrical instruments under these joint-standards is shown in the following tabulation:

Note: This tabulation covers the "pooling" of laboratory testing only, which is as yet confined to but two of the many types and sizes of instruments covered by joint standards. It should also be made clear that the tabulation covers "complete qualification" testing, which is a rather exhaustive and involved procedure for simulating all service requirements; it does not cover any "routine" testing to determine compliance with contract requirements. There is, therefore, much more still to be accomplished in the "pooling" of work.

1943	Material Laboratory				Fort Monmouth Signal Laboratory			
	2½ Inch Instruments		3½ Inch Instruments		2½ Inch Instruments		3½ Inch Instruments	
	No. Tests	No. Instrs.	No. Tests	No. Instrs.	No. Tests	No. Instrs.	No. Tests	No. Instrs.
April			1	10	2	20		
May								
June								
July			1	10	8	80		
August			4	40	12	88		
September			20	160	7	54		
October	8	80	14	124	9	50		
November	1	10	19	142	12	64		
December			11	98	2	16		
TOTAL	9	90	70	584	52	372		
1944								
January			7	52	5	51		
February			3	30	4	42		
March					1	4		
April			2	12	2	20		
May					2	20	2	20
June			4	28	2	20		
July			6	60	3	14	3	30
August			1	10			2	20
September			2	20	3	31	2	20
October			1	10	6	48	1	2
TOTAL	9	90	26	222	28	250	10	92
TOTAL (1943 & 44)	9	90	96	806	80	622	10	92

In addition to the "qualification" tests shown in the chart above, there are ten tests including 75 3½ inch instruments under way at the Material Laboratory and at the Fort Monmouth Signal Laboratory there are sixteen tests including 78 2½ inch instruments and eleven tests including 66 3½ inch instruments under way.

Our Joint-Approval Actions.

To agree upon the standards themselves is not enough. To pool the technical information upon which they are based is helpful as a step. It provides a common base upon which to stand and back them up, but it is only a step. Even to pool our laboratory facilities with each other and with Industry so that there remains no legitimate cause for argument is still but one more step, not the end. It is only when we *take common action, together*, a "joint-action" as it were, that we really begin to act as one; that is where we all play on the same team, *one team.*

But before we can do that we have to learn to think alike, to make the *same interpretations.* This is best accomplished by the use of a joint "acceptable list" by the Army and the Navy. This joint acceptable list is based upon those "qualification tests" some of which are made by the Army and some by the Navy. The resources of the Army laboratories and of the Navy laboratories having been pooled so that a test by one is considered the equivalent of a test by the other, a manufacturer's instruments which have been tested by either laboratory will receive approval from both services. This means that the individual manufacturer, in applying for tests, has to deal with but one party. Any questions raised by the tests, or any possible differences as to interpretation which may exist between the several branches of the Armed Services are studied and discussed among all concerned, so as to arrive at a consensus on all matters. To keep ourselves from "drifting apart" we keep ourselves tied together.

To date there are approximately 282 approval actions on electrical instruments, involving twenty-four manufacturers, and upon which agreements as between the Army and the Navy have been or are in process of being reached. These are being converted into "joint-actions" as rapidly as a heavy workload permits.

Joint Army-Navy Committee on Specifications.

The present unification of the Armed Services' requirements and their promulgation as "Joint-Standards" is accomplished

administratively through what is known as a *JAN Committee on Specifications* headed up as follows:

B. L. Neis, Colonel, QMC *Army Chairman*	R. L. DeGroff, Lt. Comdr., USNR *Navy Chairman*
J. A. Brockelsby, Major, QMC *Army Vice-Chairman*	K. S. Geiges, Lt. (jg), USNR *Navy Vice-Chairman*

This set-up was accomplished by a joint directive of December 22, 1942 signed by the following:

Brehon Somervell, Lieutenant General, Commanding Services of Supply *U. S. Army*	S. M. Robinson, Vice Admiral, Chief, Procurement and Material *U. S. Navy*

The actual work of technical standardization is done by many groups in the lower echelons; this story has to do with one particular group concerned with electrical measuring instruments. The philosophy, plans, ideas and administrative direction of the higher echelons mentioned above are (or could be) an excellent story in itself. The above brief reference thereto is intended here merely to acquaint the general reader with how one little project (instruments) ties in with the overall point of view.

Army-Navy Electronics Standards Agency.

An important link between the Bureau of Ships, Navy Department, and the Signal Corps, U. S. Army, is the Army-Navy Electronics Standards Agency, Red Bank, N. J. This was set up under date of January 20, 1944 by a joint directive bearing the following signatures:

H. C. Ingles, Major General, Chief Signal Officer, *U. S. Army*	E. W. Mills, Rear Admiral, U.S.N. Asst. Chief, Bureau of Ships, *U. S. Navy*

Familiarly known as "ANESA", this organization was set up to coordinate the "Communication Component Specifications" of the Signal Corps and the Bureau of Ships in order the better to serve the requirements of both services. While this is limited

to *electronic* components and whereas electrical measuring instruments are basic to all phases of electrical engineering, the 2½ inch and 3½ inch instruments are so widely used in electronic equipment as to make them one of the major components and hence must be included in "electronic" standards. This particular matter of instrument standardization is, however, not by any means limited to electronics or to ANESA; so it is necessary to further coordinate these instrument standards with all other of the many using activities in both the Army and the Navy.

The full details as to "ANESA" is another story in its own right. The author's brief reference to it herein is to show how it fits into the overall scheme of things, without any intent to treat this phase exhaustively. Suffice it to say that, in many other standards (besides instruments) it plays a vital part. The direction of ANESA activities in Red Bank, N. J. is vested in the following:

G. C. Irwin,	Paul G. Haas,
Colonel, Signal Corps,	Commander, U.S.N.
U. S. Army Co-director	*Navy Co-director*

War Production Board—American Standards Association.

The instrument standards was one of the many projects undertaken by the American Standards Association at the request of the War Production Board. It was requested by WPB under date of June 24, 1942, was initiated under date of June 27, 1942, and the first organization meeting was held in the Engineering Societies Building, 29 West 39th Street, New York, on July 23, 1943. A task group representing the Army, the Navy, Industry and ASA was formed and its first meeting was held on July 29, 1942. While this project was initiated on the assumption that the standardization of 2½ inch and 3½ inch meters was of primary importance, the discussion developed the point (made by a manufacturer) that "it was not the specifications which were causing trouble, but that inablity to anticipate demands was the chief hindrance."

This ASA task group met frequently and labored zealously from July 29, 1942 until it had obtained agreement upon the following "American War Standards":

C39.3-1943 Shock-testing Mechanism for Electrical Indicating Instruments (2½- and 3½-Inch, Round, Flush-Mounting, Panel-Type)—approved May 13, 1943.

C39.4-1943 Dimensions for External Radio-Frequency Thermocouple Converters (120 Milliamperes to 10 Amperes, Inclusive)—approved October 19, 1943.

C39.5-1943 External Ammeter Shunts for Panel-Type Instruments—approved December 29, 1943.

C75.5-1943 External Meter Resistors (Ferrule Terminal Styles)—approved June 21, 1943.

C39.2-1944 Electrical Indicating Instruments (2½- and 3½-Inch, Round, Flush-Mounting, Panel-Type)—approved January 1, 1944.

While this period has been referred to as the "WPB-ASA" era it might be more appropriate to call it the "being introduced to each other" period, or the "getting acquainted" period, because practically all the technical people concerned had actually worked on electrical instrument specifications many years before this, and they have continued to work together forever after (at least until to date). So this ASA accomplishment, great as it was, had more to do with the "human side" of the affair than it did with the purely technical side.

This brings out one of the most interesting points of the whole affair, whether one points to Navy accomplishments or Army accomplishments or ASA direction or JAN standards. It is that technical developments accomplished by *individual* initiative and the *competitive* urge often so far outrun the human, collaborative side as to lose much of their intrinsic merit. Accomplishments have to be *shared* before they do the most good. In this particular case most of the real technical accomplishments had taken place years previously, i.e., a comparison of the Navy standards of 1929 with the joint standards of 1944 show very little technical change. So the real contribution of the American Standards Association lay not in any major advances in engineering progress, but rather in "getting people together" so that they could "agree to accept" what was "already in the cards" technically speaking. That is no mean accomplishment.

ASA-1933 TO DATE (1944).

A sectional committee of the American Standards Association on Electrical Indicating Instruments was organized on June 16, 1933. This sectional committee bore (and still bears) the designation symbol of "C-39". The first draft (dated March, 1934) under this project bears an interesting "cover sheet" from which the following is taken:

AMERICAN STANDARDS ASSOCIATION
PROPOSED STANDARDS
FOR
ELECTRICAL INDICATING INSTRUMENTS.

PRELIMINARY DRAFT
MARCH, 1934

Note: Reference symbols in Parentheses refer to sources of material, as follows:

Reference Symbol	*Source*
33-	Draft No. 6 of revised AIEE Standards No. 33 for Electrical Indicating Instruments.
126-	Standards of NEMA Electrical Measuring Instrument Section.
Navy-	U. S. Navy Dept. Specifications 17-I-12 for Instruments, Electrical Measuring, Indicating, for Shipboard Use, issued Dec. 2, 1929.

AMERICAN STANDARDS
FOR
INDICATING ELECTRICAL INSTRUMENTS
CONTENTS

Four drafts of the instruments standards were prepared before final agreement was reached and the first printing made as "ASA-C39.1-1938, approved American Standards Association, July 8, 1938". The "Electrical Standards Committee" was the

sponsor for this project. The following taken from the "Foreword" are of interest in this connection:

The material contained in this American Standard has resulted from the work of the Sectional Committee on Electrical Measuring Instruments—C39 and is the first which has been approved by the American Standards Association on the subject thus far. The organizations which participated in the work and the names of their representatives are as follows:

Organization Represented	*Name of Representative*
American Institute of Electrical Engineers	E. S. Lee
	W. B. Kouwenhoven
	E. J. Rutan, Chairman
American Society for Testing Materials	Gordon Thompson
Association of American Railroads	C. J. McCarthy
Electric Light and Power Group	H. C. Koenig, Secretary
	H. R. Richardson
	E. J. Rutan, Chairman
	J. O. Coleman (Alt.)
Institute of Radio Engineers	F. H. Drake
National Electrical Manufacturers Association	G. L. Crosby
	W. N. Goodwin, Jr.
	W. H. Pratt
	H. P. Sparkes
	I. E. Hall (Alt.)
	B. R. Hill (Alt.)
Radio Manufacturers Association	John Miller
	P. K. McElroy (Alt.)
Scientific Apparatus Makers of America	E. D. Doyle
Telephone Group	R. L. Young
National Bureau of Standards	H. B. Brooks
U. S. Navy Department	Officer in Charge, Design Division, Specifications Section, Bureau of Engineering.

The basis of this standard was the American Institute of Electrical Engineers Standard for Electrical Measuring Instruments—No. 33. Material was also drawn from Standards of the Electrical Measuring Instrument Section of the National Elec-

trical Manufacturers Association and of the U. S. Navy Department. Acknowledgment is hereby made for the use of this material.

It will be observed from the foregoing that this whole instrument project is of one pattern wherever one looks; the same individuals functioned in the same field but at different levels of general participation. For example; Dr. H. B. Brooks upon certain occasions was merely "himself", upon other occasions he represented the "U. S. National Bureau of Standards", upon still others he represented the "American Institute of Electrical Engineers", and finally he was "Chairman, subcommittee 1 of Sectional Committee C39 of the ASA". Upon succeeding changes in character he had merely but to change the "direction pointed by his hat". The same was true of many others but the author hesitates to use any other specific individual as an example because they are still living and any such illustration in their cases might appear as a preference as among them.

The sectional committee C39 of the ASA is (as of 1944) still functioning. This is not to be construed as a duplication, conflict or paralleling by ASA (or others) of the "joint-standards" (JAN-Standards) of the Armed Services. They all influence and support each other, but each in its own field; and this is as it should be. More power to the ASA and all others who are sharing their ideas and efforts.

International Electrotechnical Commission.

The minutes of the meeting of the United States National Committee of the International Electrotechnical Commission, held in New York on May 28, 1930 at the Headquarters of the American Institute of Electrical Engineers contains the following report of interest in this connection:

"*Electrical Measuring Instruments.* Dr Meyer advised that several documents which had been received from the Secretariat had been referred to the Advisors and to the AIEE Technical Committee on Instruments and Measurements, and the reports will be turned over to Mr. Pratt when completed.

"The United States Navy, in December 1929, issued in tentative form test specifications for instruments which cover, to a large extent, the points raised in a questionnaire prepared by the Secretariat and distributed to the various national committees. Dr. Meyer suggested that these specifications (No. 17-I-12) be

forwarded to the Central Office for distribution as informative data, and as a contribution to the work of the advisory committee. The Committee agreed that such action is desirable, and Dr. Meyer stated that he would furnish sixty copies to Mr. Osborne for transmittal abroad."

It will be observed from the above references in the IEC minutes to "Dr. Meyer" (U. S. Bureau of Standards), to "The United States Navy," to the "AIEE" (American Institute of Electrical Engineers), and to "these specifications (17-I-12)", that there was a lot doing on *instrument standardization* in 1930. A close examination of the performance philosophy definitions, basic requirements, etc. of the standards of 1930 will show that these are essentially the same in all major respects as our "JAN-1944" editions. The significance of this fact to us in retrospect would seem to be that in the fourteen *year* period from 1930 to 1944 our progress has been primarily of a social, neighborly or "collaborative" nature, and not nearly as much of an "engineering" nature as we would like to believe.

Two days later Dr Meyer requested forty-eight additional copies of Navy Specification 17-I-12 of December 2, 1929 with the foregoing in mind. Four days prior to that meeting he had requested twelve copies, with permission to use them in that fashion. In its letter of May 24, 1930 to Dr. Meyer, granting such permission, the Bureau of Engineering had the following to say:

"The Bureau recognizes the fact that there are numerous portions of the specifications which may require modification in the light of further experience, and such modifications will be made in the succeeding printed issues as the need develops. Certain features are, in fact, frankly recognized even now as being based upon expediency rather than consistency. It is hoped, however, with the cooperation of the instrument manufacturers, to iron out these weaknesses as rapidly as practicable.

"In your distribution of these leaflets it will be appreciated if you will emphasize this point so that too much will not be expected of them. Constructive criticism is not only welcomed but solicited.

"The second point is that in the preparation of these specifications the Bureau utilized everything in the A.I.E.E. Standards which it possibly could. For certain administrative reasons

it is sometimes impracticable to refer to any non-governmental standards, and hence no reference was made in 17-I-12 to the source of any of the material contained therein.

"With the foregoing in mind the Bureau has no objection to any distribution which you see fit to make of the enclosed leaflets."

AIEE—1922 TO DATE.

The American Institute of Electrical Engineers is the "daddy" of electrical standardization in the country. There was a time, in the early days of electrical development, when the AIEE was practically the *only* organization in this country devoted to this idea. As the electrical industry "grew up", however, many other associations and groups "barged in" on this field. The AIEE has long had a "Committee on Instruments and Measurements", so the date (1922) shown above is not intended to bear upon the AIEE and its standing committees as such, but rather to show the significance of the AIEE standardization work of 1922 to Joint Army-Navy Standards of 1944. As for instruments, there is a *22 year period* of the AIEE's relationship to the Navy.

The particular significance of 1922 to this *JAN* project of 1944 is that Dr. H. B. Brooks of the U. S. National Bureau of Standards did, in 1922, have published in the AIEE Proceedings, a plea for instrument standardization. Not too many people were concerned about it in 1922, (no where near as many as were concerned in 1942-44), but it did set off two actions, viz:

(a) Reactivation of an AIEE Committee on Electrical Instruments and Measurements.

(b) Initiation of a testing and specification program for instruments by the Bureau of Engineering, Navy Department.

The two foregoing actions were not unrelated, even in their execution, because much of the AIEE committee membership simply "turned their hats around" when off duty with the AIEE and their respective organizations, and then "turned to" the Navy in the project which it had initiated. Likewise, the Navy had representation on this AIEE committee so that this representative, in turn and while off Navy duty, endeavored to contribute as much as possible to the work of the committee. The membership of the AIEE Committee on Instruments and Measurements in August 1931 consisted of the following:

Messrs. E. J. Rutan, Chairman
New York Edison Co.,
92 Vandam Street, New York, N. Y.

H. S. Baker	O. A. Knopp
O. J. Bliss	A. E. Knowlton
Perry A. Borden	H. C. Koenig
H. B. Brooks	W. B. Kouwenhoven
A. L. Cook	F. A. Laws
E. D. Doyle	Everett S. Lee
W. W. Eberhardt	J. B. Lunsford
Marion Eppley	Paul MacGahan
J. B. Gibbs	R. T. Pierce
W. N. Goodwin, Jr.	W. J. Shackelton
I. F. Kinnard	Harry L. Thomson

H. M. Turner

The committee membership between 1928 and 1935 did not alter greatly, but this was about the most active period in the history of instrument development (engineering and not political) and if one will check the activity and membership lists of the AIEE with those of the ASA, NEMA, IEC, manufacturers, etc. he will observe that a number of people had to keep "turning their hats around." In political language there was a "cell" of professional personnel working through various organizations but toward the same end. It shows the "spreading" of an idea, and the "spreadees". Engineering ideals spread like political ones, only it takes much longer because engineers are not very gregarious as a class—they tend too greatly toward individualism, thus their progress is slower.

The Electrical Instrument Manufacturers.

Beginning with an "embarrassing situation" in 1924, as will be related later on herein, and carrying through to 1929, there ensued a program of very close cooperation between the Bureau of Engineering, Navy Department, and the electrical instrument manufacturers. The manufacturers took a most active part in helping us to raise instrument standards; then they in turn redesigned many of their instruments to conform to the new standards; making available to other users in civilian industry the technical improvements resulting from government needs.

This one of the hundreds of our electrical material and equipment specifications of that era, was the one which the manufacturers and users were most likely to swear by and not at. This was a most unusual situation as regards a "government specification" and a manufacturers' feelings. The answer to this anamalous condition was that this specification was a part of them, a bit of their own handiwork as partners in a joint enterprise; they had been asked for and had rendered their best advices. The electrical instrument manufacturers as a whole have never faulted in their course of cooperation with the Navy throughout the twenty year period from 1924 to 1944.

U. S. National Bureau of Standards.

It was in 1922 that Dr. H. B. Brooks, then in charge of the instruments section of the U. S. National Bureau of Standards, published some of his own views on the subject of instrument standardization in the Proceedings of the American Institute of Electrical Engineers. Dr. Brooks had a good idea but outside of its publication in the AIEE he did not at that time have the means to put it into immediate and practical use because the Bureau of Standards was not a "using agency" in the usual sense. Except for the Navy there was no apparent interest in this subject among other government departments. Its interest was confined to a limited "professional" field. The Navy, being a large using agency was, however, confronted with this problem of standardization, so a Navy representative teamed up with Dr. Brooks so as to put that idea to some use.

The essence of this idea of Dr. Brooks was to "define" what it was we were talking about when we referred to instruments. It was to develop a "set of definitions" so that if two or more people with instruments in mind got together they could speak a *common language.* Heretofore engineers generally, in specification writing, picked out some "design features" which were more or less proprietary to the product of certain manufacturers and called it a day. Not knowing exactly how to express what they really wanted, the engineers attempted to cover up that ignorance by calling for what, at the time, impressed them individually as being good design. In short, the usual specification approach represented the "opinions" of the engineer using instruments or the opinions of some salesman who made up his mind for him.

The Navy program was to state its several needs in terms of

instrument "performance", leaving to all manufacturers the opportunity of applying their best judgment, in whatever design practices possible, in order to achieve the desired end result. That type of specification requires a considerable degree of "definition" in order that all may talk in a common language, the language of "needs" rather than the language of sales. Furthermore, and this is the most important feature of all, it requires a tremendous amount of testing, of a totally unbiased character, in a laboratory having adequate facilities for simulating service conditions. Talking the same language then, and substituting laboratory tests for opinions, we all (including the manufacturers themselves) started out to work up one of the first truly "performance" type specifications ever developed for electrical measuring instruments. Electrical measuring instruments are designed to test or measure quantitively, they do not render opinions; they are designed to give numerical facts whatever they may be. It was, therefore, appropriate that the standards for our fact finding tools (instruments) be themselves specified upon a fact finding basis. This may sound simple, but the idea at that time was rather new and novel.

The contributions of the Bureau of Standards, particularly in the philosophy of certain key personnel, such as Doctors Brooks, Meyers, Silsbee, etc., were valuable ones; not merely at the beginning of the project but later on through their continuing association with similar projects of the American Institute of Electrical Engineers, the American Standards Association, the National Electrical Manufacturers' Association, the United States National Committee of the International Electrotechnical Commission, etc. All of these acts contributed to or influenced the Navy effort on instrument standards.

"Once Upon a Time".

But now comes the "pay off"; this is where the "acorn was buried". Once upon a time (1922 to be specific) there was a much smaller bureau (Bureau of Engineering) than the present one (Ships). Two (of many) people worked in this smaller Bureau, one concerned with "Radio" and the other with "Electrical" applications generally. Because "Radio" was one organization and "Electrical" another, these two men did not know each other; in fact each had "never heard of" the other one, although both were in the same building not too many feet apart

"down the hall". But, in line with their organizational duties, each tending strictly to his own business, each one "going it alone", the pet subject of both was *electrical instruments*. It was both easy and (at that time) a rather popular idea, to "live and let live". In that atmosphere one might avoid a "scrap" (it was 1924, just two years after 1922).

There came a day, however, when an *irate* manufacturer called at the Bureau seeking enlightenment on two letters he had just received. Says he, "I have here two letters, both having the same letterhead (Bureau of Engineering), both bearing the same date (October, 1924), and both signed 'By Direction, Chief of Bureau'. Yet one of these letters says that my instrument 'has been found satisfactory and is approved for Naval use', but this other one says that it 'has been found unsatisfactory and is disapproved for Naval use'. Now tell me if you please, what am I supposed to do, where do I go from here?"

Whereupon the engineer so addressed, promising to "look into" this thing, relieves himself of the manufacturer's presence at the earliest opportunity, examines the "code" or "flag" on the other fellow's letter so as to "locate" him, then proceeds down the hall bent upon a social call. "Introducing" himself to the "other fellow", he is surprised to find a chap neither too hard to talk to nor too altogether dumb about electrical instruments; in fact a rather charming fellow.

The word got out, of course, and the Chief of Bureau did not see the joke; in fact he directed that a rather drastic administrative "order" be prepared for his signature. Even worse, one of the culprits had to draft the order; it was one lesson he took to heart. The author has a very clear recollection of the whole affair; he gave the "soft answer" to the manufacturer (and others), he "introduced" himself "down the hall", and he prepared the draft of the "order"; in short "he was there, Charlie", so he remembers.

In Conclusion.

The reader is invited to draw his own conclusions. If he is left in any doubt may the author suggest that, starting from this point, he try going backward (from the end to the beginning). If he then concludes that the best way to let an *idea* grow up is to *take on some partners*, and keep on *adding* them, the purpose of this article will have been accomplished. It takes a lot of time

and care, by a lot of people, to "bring up" one little idea to the point where it can safely be left "on its own". And the most worthwhile advances sometimes come from "mistakes" or errors made by individuals but corrected through group effort.

IN ACKNOWLEDGMENT.

The author is indebted to his secretary, Miss Molly Feece, for her patient assistance in the collection and arrangement of the text of this article. As the proud, though once chastened "nursemaid" of the 1924 infant which in 1944, at age 20, is now grown to maturity as a series of JAN Standards, the author is indebted to all these dozens of other friends and neighbors in the Army, Navy, ASA, AIEE, IEC and in Industry, for their zeal and skill in helping to "raise" it. In fact were it not for these many "other fellows". there might have been nothing to write about, hence nothing to "author". To all who made this possible, thanks.

SEA-GOING INCINERATORS.

By Raymond W. Hiteshue.*

The above title immediately suggests a ghastly topic and unfortunately has more or less placed an important problem in the category of other orphans of the engineering world. Previous to the present war it was a simple matter to dispose of ship's garbage and trash by merely throwing all to the four winds and the sea. Obviously, this could no longer be done with the advent of war—their tell-tale path acting as a first-class sign post for preying underwater craft. Upon investigation of methods to prevent visual evidence, it was found that garbage disposal proved rather easy, the successful method being that of grinding and forcing it (under high pressure) through the ship's bottom, the fine particles upon rising being disseminated throughout a very large area. Cans and other metallic containers were simply compressed and thrown overboard. The riddance of paper and wood, however, proved rather complicated. They could have been bundled and submerged with weights but the necessary ballast would be prohibitive since the average capital ship releases about 2000-2500 pounds per day. Storing, followed by dumping in friendly waters, was another suggestion but this would have been very painstaking and also would have been a serious drain on the already overburdened crews. Burning, therefore, seemed to be the practical answer; the object of this article is to bring out some of the difficulties of this supposedly simple disposal procedure.

Two prerequisites of a sea-going incinerator were that combustion be accomplished without the slightest trace of smoke and that passage of flue gases to the atmosphere be sparkless. Space and weight factors, together with simplicity of operation and maintenance, were also important limitations. Four general designs have been exploited, viz., natural draft units, forced draft with closed firerooms, forced draft with open firerooms,

*Assistant Mechanical Engineer, Naval Boiler & Turbine Laboratory, Navy Yard, Philadelphia, Pa.

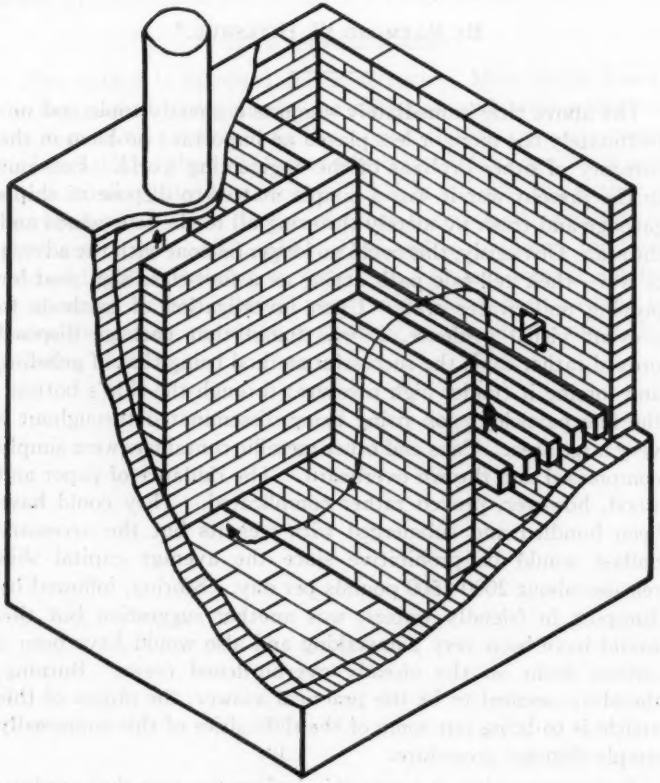


FIG. 1

NATURAL DRAFT UNIT

and induced draft with open firerooms. Each of these arrangements will be discussed separately in the following paragraphs.

Figure 1 is an isometric sketch of a natural draft unit. It is simply a refractory-lined box divided to form a combustion chamber and a two-pass gas compartment. Fixed grates are usually employed with the grate area designed for a firing rate of 25-30 pounds per hour per square foot. Drying hearths or step-grates are not necessary since all firing material is relatively dry. The function of the gas-pass section (usually two passes) is to lengthen the gas travel with simultaneous flow reversal—both factors enhancing the removal of flue gas particles. Primary air is admitted through the ash pit door with secondary air supplied through apertures around the fire bed. Smokeless operation can easily be attained with this type unit but unfortunately its capacity (150-200 pounds per hour maximum) is limited due to low air flow. The stack draft obtainable while utilizing a straight stack of, say, 25 feet, and maintaining an exit gas temperature of around 900 degrees F., would be only 0.10 inches of water. Since practically all shipboard installations are required to use stacks consisting of several bends and long runs, it is obvious that natural draft burners can find use on only small craft. The weight of a 200-pound per hour unit would be about 8000 pounds and would occupy a box volume of 145 cubic feet.

Figure 2 shows a forced draft design operating within a closed fireroom—a type representative of those currently in service use. The burner proper is practically identical to a natural draft model except that it is located within an air-tight compartment fitted with air locks appropriate for admission of personnel and charging material. An externally-located blower discharges directly into the compartment and air admission for combustion is made in the conventional manner. No difficulties are experienced with such a set-up and units as large as 500 pounds per hour have been used successfully. Fireroom pressure necessary (assuming a tight compartment) for maintenance of a 500-pound per hour rate is 1.50 inches of water. This value is possible when employing a short, straight stack. In practice, a stack resistance of 0.5 to 1.0 inch of water is usually encountered. Air pressure drop through the system (ash pit to gas exit) is about 1.10 inches of water when supplying 2800 c.f.m. Although the latter value is well in excess of that required for smokeless

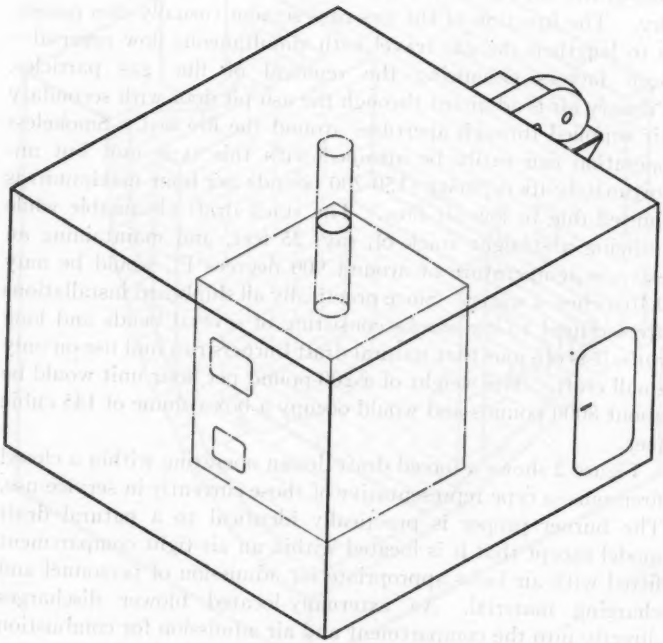


FIG. 2

FORCED DRAFT - CLOSED FIREROOM

operation, the excess is utilized for cooling the products of combustion to an acceptable figure since no other means for dissipation is provided. Stack temperatures average 900 degrees F. with 1300 degrees F. being approached momentarily upon charging. Grate areas are designed for 50 pounds per hour per square foot. Two disadvantages are inherent with this incinerator, viz.: (1) conditions are very unpleasant to operating personnel and (2) the compartment construction entails additional problems to the ship designer. Ambient air temperatures within the compartment range from 120-140 degrees F., temperatures at which no man can work efficiently or comfortably. In practice, men are prone to overload the firebox and withdraw quickly—an act causing heavy smoke since the air supply is sufficient for only small periodic charges. The air-tight compartment spells many hours of careful construction and use of specially designed air lockers.

Although the above unit (closed fireroom system) has been "carrying the ball," engineers thought it a worthy idea to try an air-encased burner, i.e., one having a closely fitting (6 inches space) casing into which air is received from a forced draft blower —very similar to the present air-encased marine boiler arrangement. A sketch of this is shown in Figure 3. With a short straight stack, one which will permit furnace pressures below 0.5 inch of water, excellent results were achieved. However, when the furnace pressure exceeds that value, flarebacks will occur whenever the firing door is opened. It was first believed that the blower could be secured, or throttled, when firing but trials showed that resulting smoking tendencies could not be tolerated. Augmenters, such as steam jets installed at the stack base, did not materially alleviate this condition. Thus, the forced draft, air-encased burner was immediately ruled ineligible for service use.

Since the only objection to the forced draft, open fireroom combination was that air flow had to be secured during charging, it seemed logical that an induced draft blower would be the answer to an engineer's prayer. Figure 4 shows an arrangement of such a design and, in reality, it is simply the natural draft unit with the stack led into the blower's intake. Smokeless operation can easily be maintained with this arrangement at all times. Since no heat exchanger is used in the stack, the temperature of all gases entering the blower must be held to around

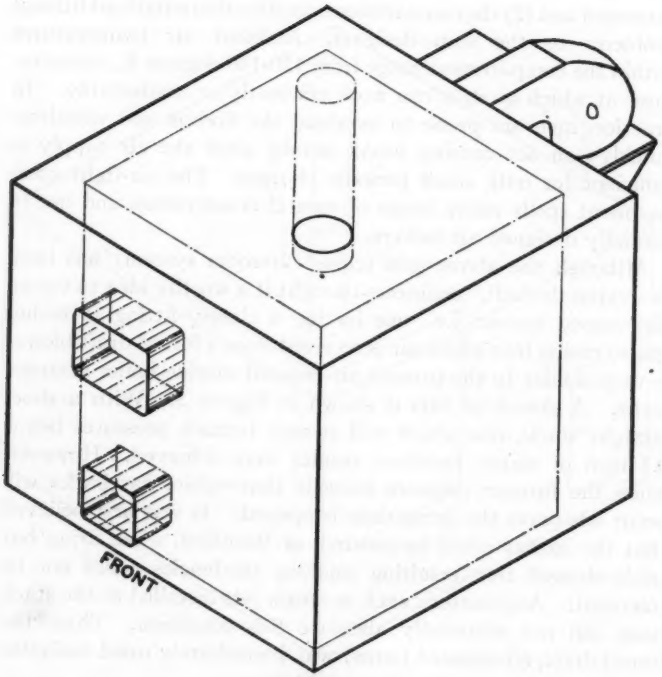


FIG.-3
FORCED DRAFT-OPEN FIREROOM.

1000 degrees F. unless stainless steel or other high chrome-nickel alloy is used in the construction of the blower. Cooling of the gases is a relatively simple procedure and can best be obtained by bleeding in diluting air before the inlet. With a 500-pounds per hour unit, the firebox pressure would be about −0.15 inch of water with −0.70 inch at the gas exit. This particular unit (induced flow) should undoubtedly be the solution to the problem. The only argument that possibly could be advanced against it would be that the blower size would be larger and may require more cautious operation. Both factors, however, are minor and can certainly be tolerated.

Since sparking characteristics are common to all types of burners, a summation of this phase will be made. Experience to date has shown that it is practically impossible completely to eliminate sparks when firing 300-500 pounds per hour. Sparks become noticeable at dusk and at night, they may be seen traveling 25-50 feet above the stack top and may drift as far as 300-400 yards. This characteristic definitely limits the period of operation to daylight hours only. Even during daytime operation it presents quite a fire hazard to aircraft carriers and other vessels carrying light fuels. Use of stack screens was of little use, burning out rapidly and clogging—the latter introducing a prohibitive resistance to gas flow. Use of multiple gas passes, together with various types of baffles, was also worthless and only added to the pressure loss through the system. Injection of atomized water into the stack proved to be the most effective attack but required enormous quantities of water. When firing 500 pounds per hour, an injection of about 10,000 pounds of water per hour is required for absolute sparkless operation. Use of large quantities of water, however, produces an artificial rain —serious enough to impair shipboard operations. The reader will no doubt wonder why it is so difficult to arrest these sparking particles (actually charred wood), but when it is considered that their velocity is about 1000-1500 feet per minute it is understandable. When using baffles or other deflecting devices, they simply race around these surfaces and continue onward. When spraying water across a section in the stack, the free area is reduced tremendously and the particles may attain a velocity in the section of around 10,000 feet per minute. Thus, the particles bunch together and shoot through the voids in the spray, the water being effective only at the peripheries of these voids.

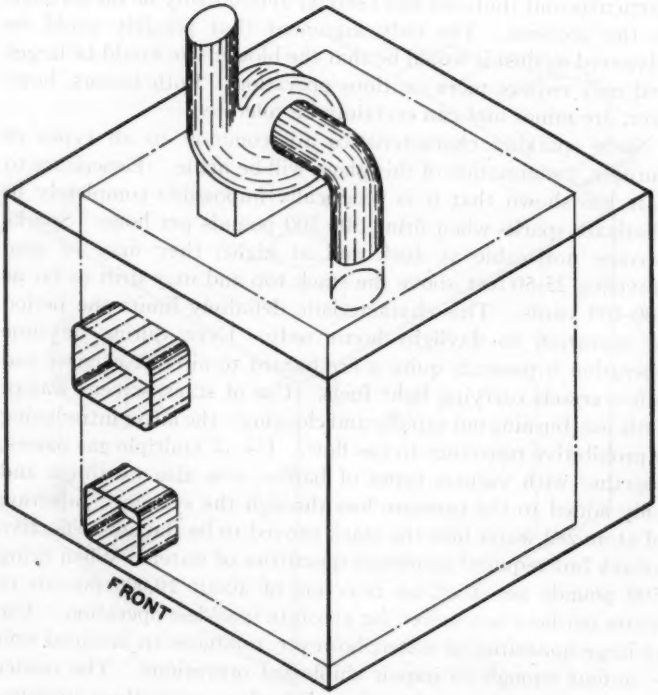


FIG. 4

INDUCED DRAFT - OPEN FIREROOM

From the above discussion we might conclude that the ultimate design might be a large box-like, refractory-lined compartment incorporating a very large gas exit, a heat exchanger and an induced draft blower. Omission of the separate gas pass section would also be in order. With a large firebox section (125 cubic feet for 500 pounds per hour unit) and a large gas exit (30 inches in diameter), gas velocities would be reduced tremendously and fly particles would have an excellent chance of burning to completion in the chamber—a factor which should certainly minimize or possibly eliminate spark emission. An extended surface heat exchanger placed at the base of the stack could be designed to effect a 500 degrees F. reduction in gas temperature and thus eliminate the necessity of cooling air for the induction blower. Introduction of the exchanger would entail an added pressure loss to the system but would probably be balanced by the reduction of pressure loss gained as the result of eliminating the gas pass compartment and through use of a larger gas exit. Water from the ship's fire mains could be piped to the exchanger in quantities sufficient to hold the outlet temperature of the water in the vicinity of 175 degrees F.—a temperature at which scale-forming materials would still stay in solution. If this were deemed undesirable, it would be a simple matter to install a small electrically-driven pump.

A word to the operating personnel would seem worthwhile at this juncture. Grates and ash pits should be cleaned religiously after every eight hours' operation. The combustion of paper and wood results in the formation of a thick sealing slag or ash and after 8-10 hours' operation will seriously restrict the flow of air through the grates. Firing charges should be made up in accordance with the designed firing rate and fired at regular time intervals. This is of utmost importance for maintenance of smokeless operation. Engineer officers should instruct their men in the theory of operation and care of the equipment and, furthermore, they should instill them with the importance of their duties and discourage attempts to draw trash burner crews from work parties or extra duty groups.

CALCULATION OF THE IMPEDANCE PROPERTIES OF PARASITIC ANTENNA ARRAYS INVOLVING ELEMENTS OF FINITE RADIUS.

By Lieut. Commander Charles W. Harrison, Jr.
E(L)-T U. S. N. R.

Summary: After a brief resumé of a general theory for the current in coupled antennas, expressions are derived for the distribution of current along two parallel antennas of unequal length and radius. The input impedance to each antenna is then determined when the antennas are driven in phase, and in phase opposition, for applied voltages of equal magnitude. Conventional circuital relations for coupled systems yield the self-impedance of each radiator, and mutual impedance, in terms of these four calculated impedances.

Methods for obtaining optimum conditions in two element arrays, consisting of a driven antenna in proximity to a director or reflector are considered.

General Theory for the Current in Coupled Antennas.

An array, consisting of two symmetrical center-driven antennas oriented parallel to the z axis of a system of coordinates, is shown in Figure (1). Element (1) has a half-length h_1 and radius a_1; element (2) has a half-length h_2 and radius a_2; and the distance between elements is b. The axis of each antenna makes a right angle to the line connecting the geometrical centers of the radiators ($z = 0$). The assumption is made that the antennas are perfectly conducting. This is a good approximation in practice, as most of the power supplied to a well constructed antenna is transferred into space. In previous analyses[1-4] it is shown that the continuity of the tangential component of electric field at the surface of antenna (1), for example, requires that the total

1. Ronold King and Charles W. Harrison, Jr., "The Distribution of Current Along a Symmetrical Center-Driven Antenna," Proc. I. R. E., Vol. 31, No. 10, pp. 548-567; October, 1943.
2. Ronold King and Charles W. Harrison, Jr., "Mutual and Self-Impedance for Coupled Antennas," Jour. Appl. Phys., Vol. 15, No. 6, pp. 481-495; June, 1944.
3. Charles W. Harrison, Jr., "Mutual and Self-Impedance for Colinear Antennas," accepted for publication in Proc. I. R. E.
4. Charles W. Harrison, Jr., "On the Distribution of Current Along Asymmetrical Antennas," accepted for publication in Jour. Appl. Phys.

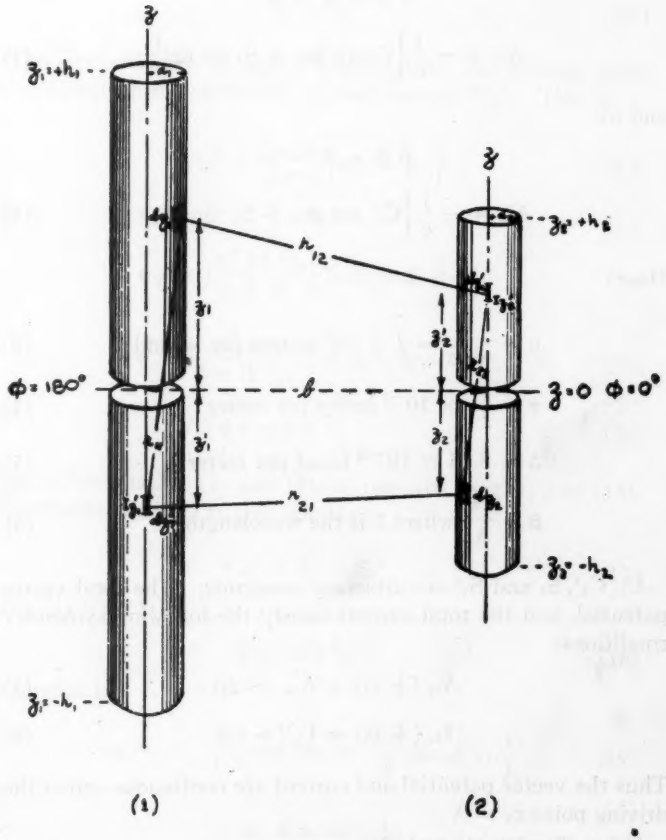


FIGURE 1.

vector potential distribution along the radiator satisfy the following equations:

For

$$0 \leqq z_1 \leqq + h_1$$

$$A_{1z} = -\frac{j}{c}\left\{C_1 \cos \beta z_1 + S_1 \sin \beta z_1\right\} \tag{1}$$

and for

$$0 \geqq z_1 \geqq - h_1$$

$$A_{1z} = -\frac{j}{c}\left\{C_1' \cos \beta z_1 + S_1' \sin \beta z_1\right\} \tag{2}$$

Here

$$c = \frac{1}{\sqrt{\pi\Delta}} = 3 \times 10^8 \text{ meters per second} \tag{3}$$

$$\pi = 4\pi \times 10^{-7} \text{ henry per meter} \tag{4}$$

$$\Delta = 8.85 \times 10^{-12} \text{ farad per meter} \tag{5}$$

$$\beta = \frac{2\pi}{\lambda}, \text{ where } \lambda \text{ is the wavelength} \tag{6}$$

C_1, C_1', S_1 and S_1' are arbitrary constants. The total vector potential, and the total current satisfy the following symmetry conditions:

$$A_{1z}(+ z_1) = A_{1z}(- z_1) \tag{7}$$

$$I_{1z}(+ z_1) = I_{1z}(- z_1) \tag{8}$$

Thus the vector potential and current are continuous across the driving point $z_1 = 0$.

Using (7) with (1) and (2),

$$C_1 \cos \beta z_1 + S_1 \sin \beta z_1 = C_1' \cos \beta z_1 - S_1' \sin \beta z_1 \tag{9}$$

or

$$(C_1 - C_1') \cos \beta z_1 + (S_1 + S_1') \sin \beta z_1 = 0 \tag{10}$$

Since $\cos \beta z_1$ and $\sin \beta z_1$ are linearly independent functions, it follows that

$$C_1 = C_1' \tag{11}$$

$$S_1 = S_1' \tag{12}$$

The discontinuity in scalar potential at the driving point ($z_1 = 0$) equals the externally applied voltage V_{10}^e. That is

$$V_{10}^e = \underset{z_1 \to 0}{\text{Limit}} \left\{ \phi_+ - \phi_- \right\} \tag{13}$$

where

$$\phi_+ = j \frac{c^2}{\omega} \left\{ \frac{\delta A_{1z}}{\delta z_1} \right\} \quad 0 \leqq z_1 \leqq + h_1 \tag{14}$$

$$\phi_- = j \frac{c^2}{\omega} \left\{ \frac{\delta A_{1z}}{\delta z_1} \right\} \quad 0 \geqq z_1 \geqq - h_1 \tag{15}$$

$$\omega = 2 \pi f = c \beta \tag{16}$$

Upon differentiating (1) and (2), as required by (14) and (15), and substituting in (13), one obtains

$$V_{10}^e = S_1 - S_1' \tag{17}$$

Using (17 with (12),

$$V_{10}^e = 2 S_1 \tag{18}$$

To summarize

$$A_{1z} = - \frac{j}{c} \left\{ C_1 \cos \beta z_1 + \frac{V_{10}^e}{2} \sin \beta / z_1 / \right\} \tag{19}$$

for

$$- h_1 \leqq z_1 \leqq + h_1$$

In an entirely analogous manner the total vector potential distribution along radiator (2) may be written

$$A_{2z} = - \frac{j}{c} \left\{ C_2 \cos \beta z_2 + \frac{V_{20}^e}{2} \sin \beta / z_2 / \right\} \tag{20}$$

for

$$-h_2 \leqq z_2 \leqq +h_2.$$

Here V_{20}^e is the voltage applied at the driving point $z_2 = 0$.

The vector potential at the surface of each antenna consists of two components: that due to the current in the antenna itself, and that due to the current in the parallel antenna. Thus

$$A_{1z} = A_{11z} + A_{12z} \tag{21}$$

$$A_{2z} = A_{22z} + A_{21z} \tag{22}$$

with

$$A_{11z} = \frac{\pi}{4\pi} \int_{-h_1}^{+h_1} I_{1z}' \frac{e^{-j\beta r_{11}}}{r_{11}} dz_1' \tag{23}$$

$$A_{12z} = \frac{\pi}{4\pi} \int_{-h_2}^{+h_2} I_{2z}' \frac{e^{-j\beta r_{12}}}{r_{12}} dz_2' \tag{24}$$

$$A_{22z} = \frac{\pi}{4\pi} \int_{-h_2}^{+h_2} I_{2z}' \frac{e^{-j\beta r_{22}}}{r_{22}} dz_2' \tag{25}$$

$$A_{21z} = \frac{\pi}{4\pi} \int_{-h_1}^{+h_1} I_{1z}' \frac{e^{-j\beta r_{21}}}{r_{21}} dz_1' \tag{26}$$

The following notation is used:

$$r_{11} = \sqrt{(z_1 - z_1')^2 + a_1^2} \tag{27}$$

$$r_{12} = \sqrt{(z_1 - z_2')^2 + b^2} \tag{28}$$

$$r_{22} = \sqrt{(z_2 - z_2')^2 + a_2^2} \tag{29}$$

$$r_{21} = \sqrt{(z_2 - z_1')^2 + b^2} \tag{30}$$

Using (23) and (24) in (21), and equating to (19),

$$\int_{-h_1}^{+h_1} I_{1s}' \frac{e^{-j\beta r_{11}}}{r_{11}} dz_1' + \int_{-h_2}^{+h_2} I_{2s}' \frac{e^{-j\beta r_{12}}}{r_{12}} dz_2' = - j\frac{4\pi}{R_c}\left\{C_1 \cos \beta z_1 + \frac{1}{2} V_{10}^e \sin \beta/z_1/\right\} \quad (31)$$

Similarly, (25) and (26) in (22), equated to (20) gives

$$\int_{-h_2}^{+h_2} I_{2s}' \frac{e^{-j\beta r_{22}}}{r_{22}} dz_2' + \int_{-h_1}^{+h_1} I_{1s}' \frac{e^{-j\beta r_{21}}}{r_{21}} dz_1' = - j\frac{4\pi}{R_c}\left\{C_2 \cos \beta z_2 + \frac{1}{2} V_{20}^e \sin \beta/z_2/\right\} \quad (32)$$

$$R_c = \sqrt{\frac{\pi}{\Delta}} = 376.7 \backsimeq 120\,\pi \text{ ohms} \quad (33)$$

The integral equation (31) when expanded as in previous papers on coupled antennas, yields the current I_{1s}. Thus

$$I_{1s} = - j\frac{4\pi}{\Omega_1 R_c}\left\{C_1 \cos \beta z_1 + \frac{1}{2} V_{10}^e \sin \beta/z_1/\right\} - \frac{1}{\Omega_1}\left\{I_{1s} ln\left(1 - \frac{z_1^2}{h_1^2}\right) + I_{1s}\delta_1 + \int_{-h_1}^{+h_1} \frac{I_{1s}' e^{-j\beta r_{11}} - I_{1s}}{r_{11}} dz_1' + \int_{-h_2}^{+h_2} I_{2s}' \frac{e^{-j\beta r_{12}}}{r_{12}} dz_2'\right\} \quad (34)$$

where

$$\Omega_1 = 2\, ln \frac{2\,h_1}{a_1} \quad (35)$$

$$\delta_1 = ln\left\{\frac{1}{4}\left(\sqrt{1 + \left(\frac{a_1}{h_1 - z_1}\right)^2} + 1\right)\left(\sqrt{1 + \left(\frac{a_1}{h_1 + z_1}\right)^2} + 1\right)\right\} \quad (36)$$

The expressions for I_{2s}, Ω_2 and δ_2 are like those given above with 2 written for 1 and 1 for 2 in the subscripts.

The current I_{1s} vanishes at $z_1 = \pm h_1$, and inasmuch as

$$ln\left(1 - \frac{z_1^2}{h_1^2}\right) + \delta_1$$

remains finite there, (34) reduces to the following value at $z_1 = + h_1$.

$$0 = -j\frac{4\pi}{\Omega_1 R_c}\left\{C_1 \cos \beta h_1 + \frac{1}{2} V_{10}^e \sin \beta h_1\right\} - \frac{1}{\Omega}\left\{\int_{-h_1}^{+h_1} I_{1s}' \frac{e^{-j\beta r_{11h}}}{r_{11h}} dz_1' + \int_{-h_2}^{+h_2} I_{2s}' \frac{e^{-j\beta r_{12h}}}{r_{12h}} dz_2'\right\} \quad (37)$$

The notation

$$\left.\begin{aligned} r_{11h} &= \sqrt{(h_1 - z_1')^2 + a_{12}} \\ r_{12h} &= \sqrt{(h_1 - z_2')^2 + b^2} \end{aligned}\right\} \quad (38)$$

is employed.

Upon subtracting (37) from (34),

$$I_{1s} = \frac{-j4\pi}{\Omega_1 R_c}\left\{C_1 (\cos \beta z_1 - \cos \beta h_1) + \frac{1}{2} V_{10}^e (\sin \beta / z_1 / - \sin \beta h_1)\right\} - \frac{1}{\Omega_1}\left\{[I_{1s}]_0 ln\left(1 - \frac{z_1^2}{h_1^2}\right) + [I_{1s}]_0 \delta_1 + \int_{-h_1}^{+h_1} \frac{[I_{1s}']_0 e^{-j\beta r_{11}} - [I_{1s}]_0}{r_{11}} dz_1' - \int_{-h_1}^{+h_1} [I_{1s}']_0 \frac{e^{-j\beta r_{11h}}}{r_{11h}} dz_1'\right\} - \frac{1}{\Omega_1}\left\{\int_{-h_2}^{+h_2} [I_{2s}']_0 \frac{e^{-j\beta r_{12}}}{r_{12}} dz_2' - \int_{-h_2}^{+h_2} [I_{2s}']_0 \frac{e^{-j\beta r_{12h}}}{r_{12h}} dz_2'\right\} \quad (39)$$

The expression for I_{2s} is like (39) with subscripts 1 and 2 interchanged. The zeroth order approximations to the correct distributions of current are implied by the symbol $[\ ]_0$. These are

$$[I_{1s}]_0 = -j\frac{4\pi}{\Omega_1 R_c}\left\{C_1 (\cos \beta z_1 - \cos \beta h_1) + \frac{1}{2} V_{10}^e (\sin \beta / z_1 / - \sin \beta h_1)\right\} \quad (40)$$

$$[I_{2s}]_0 = -j\frac{4\pi}{\Omega_2 R_c}\left\{C_2(\cos\beta z_2 - \cos\beta h_2) + \frac{1}{2}V_{20}^{e}(\sin\beta/z_2/ - \sin\beta h_2)\right\} \quad (41)$$

Equations (40) and (41) (with z primed where required) are to be appropriately used in (39) *as well as in* (37).

For convenience let the following notation be introduced:

$$F_0(z_1) = \cos\beta z_1,\ G_0(z_1) = \sin\beta/z_1/ \quad (42)$$

$$F_{0s1} = F_0(z_1) - F_0(h_1),\ G_{0s1} = G_0(z_1) - G_0(h_1) \quad (43)$$

$$F_1(z_1) = -\left\{F_{0s1}\,ln\left(1 - \frac{z_1^2}{h_1^2}\right) + F_{0s1}\,\delta_1 + \int_{-h_1}^{+h_1}\frac{F_{0s1}'\,e^{-j\beta r_{11}} - F_{0s1}}{r_{11}}dz_1'\right\} \quad (44)$$

$$F_1(h_1) = -\int_{-h_1}^{+h_1} F_{0s1}'\frac{e^{-j\beta r_{11h}}}{r_{11h}}dz_1' \quad (45)$$

$G_1(z_1)$ is like $F_1(z_1)$ with G written for F; $G_1(h_1)$ is like $F_1(h_1)$ with G written for F.

$$P_1(z_1) = -\int_{-h_2}^{+h_2} F_{0s2}'\frac{e^{-j\beta r_{12}}}{r_{12}}dz_2' \quad (46)$$

$$P_1(h_1) = -\int_{-h_2}^{+h_2} F_{0s2}'\frac{e^{-j\beta r_{12h}}}{r_{12h}}dz_2' \quad (47)$$

$$Q_1(z_1) = -\int_{-h_2}^{+h_2} G_{0s2}'\frac{e^{-j\beta r_{12}}}{r_{12}}dz_2' \quad (48)$$

$$Q_1(h_1) = -\int_{-h_2}^{+h_2} G_{0s2}'\frac{e^{-j\beta r_{12h}}}{r_{12h}}dz_2' \quad (49)$$

Additionally, let

$$\left.\begin{aligned} F_{1z1} &= F_1(z_1) - F_1(h_1) \\ G_{1z1} &= G_1(z_1) - G_1(h_1) \end{aligned}\right\} \tag{50}$$

$$\left.\begin{aligned} P_{1z1} &= P_1(z_1) - P_1(h_1) \\ Q_{1z1} &= Q_1(z_1) - Q_1(h_1) \end{aligned}\right\} \tag{51}$$

An analogous set of expressions obtain for

$$F_{1z2},\ G_{1z2},\ P_{1z2} \text{ and } Q_{1z2}.$$

Using the above notation, (40) becomes

$$[I_{1z}]_0 = -\,j\,\frac{4\pi}{\Omega_1 R_c}\left\{C_1 F_{0z1} + \frac{1}{2} V_{10}{}^e G_{0z1}\right\} \tag{52}$$

and (41) is given by

$$[I_{2z}]_0 = -\,j\,\frac{4\pi}{\Omega_2 R_c}\left\{C_2 F_{0z2} + \frac{1}{2} V_{20}{}^e G_{0z2}\right\} \tag{53}$$

Upon substituting (52) and (53) in (39) and taking cognizance of (42) to (51),

$$I_{1z} = -\,j\,\frac{4\pi}{\Omega_1 R_c}\left\{C_1\left(F_{0z1} + \frac{F_{1z1}}{\Omega_1}\right) + \frac{1}{2} V_{10}{}^e\left(G_{0z1} + \frac{G_{1z1}}{\Omega_1}\right) + C_2 \frac{P_{1z1}}{\Omega_2} + \frac{1}{2} V_{20}{}^e \frac{Q_{1z1}}{\Omega_2}\right\} \tag{54}$$

The corresponding expression for I_{2z} is

$$I_{2z} = -\,j\,\frac{4\pi}{\Omega_2 R_c}\left\{C_2\left(F_{0z2} + \frac{F_{1z2}}{\Omega_2}\right) + \frac{1}{2} V_{20}{}^e\left(G_{0z2} + \frac{G_{1z2}}{\Omega_2}\right) + C_1 \frac{P_{1z2}}{\Omega_1} + \frac{1}{2} V_{10}{}^e \frac{Q_{1z2}}{\Omega_1}\right\} \tag{55}$$

Evaluation of the Constants C_1 and C_2.

Perhaps the most important step in the solution of the current equations consists in the determination of the constants C_1 and C_2. This is achieved in the following way: Using the adopted

short-hand, (37) [for antenna (1)], and its equivalent [for antenna (2)] are

$$0 = -j\frac{4\pi}{\Omega_1 R_c}\left\{C_1\left(F_0(h_1) + \frac{F_1(h_1)}{\Omega_1}\right) + \frac{1}{2}V_{10}^{e}\left(G_0(h_1) + \frac{G_1(h_1)}{\Omega_1}\right) + C_2\frac{P_1(h_1)}{\Omega_2} + \frac{1}{2}V_{20}^{e}\frac{Q_1(h_1)}{\Omega_2}\right\} \quad (56)$$

$$0 = -j\frac{4\pi}{\Omega_2 R_c}\left\{C_2\left(F_0(h_2) + \frac{F_1(h_2)}{\Omega_2}\right) + \frac{1}{2}V_{20}^{e}\left(G_0(h_2) + \frac{G_1(h_2)}{\Omega_2}\right) + C_1\frac{P_1(h_2)}{\Omega_1} + \frac{1}{2}V_{10}^{e}\frac{Q_1(h_2)}{\Omega_1}\right\} \quad (57)$$

Equations (56) and (57) are easily solved simultaneously for C_1 and C_2. Neglecting terms with the coefficients

$$\frac{1}{\Omega_1^2},\ \frac{1}{\Omega_2^2},\ \text{and}\ \frac{1}{\Omega_1\,\Omega_2},$$

and defining

$$N_1 = F_0(h_2)\,G_0(h_1) + F_0(h_2)\frac{G_1(h_1)}{\Omega_1} + G_0(h_1)\frac{F_1(h_2)}{\Omega_2} \quad (58)$$

$$N_2 = F_0(h_1)\,G_0(h_2) + F_0(h_1)\frac{G_1(h_2)}{\Omega_2} + G_0(h_2)\frac{F_1(h_1)}{\Omega_1} \quad (59)$$

$$M_1 = \frac{1}{\Omega_2}\left\{F_0(h_2)\,Q_1(h_1) - G_0(h_2)\,P_1(h_1)\right\} \quad (60)$$

$$M_2 = \frac{1}{\Omega_1}\left\{F_0(h_1)\,Q_1(h_2) - G_0(h_1)\,P_1(h_2)\right\} \quad (61)$$

$$D = F_0(h_1)\,F_0(h_2) + F_0(h_2)\frac{F_1(h_1)}{\Omega_1} + F_0(h_1)\frac{F_1(h_2)}{\Omega_2} \quad (62)$$

one obtains:

$$C_1 = -\frac{1}{2}\left\{\frac{V_{10}^{e}\,N_1 + V_{20}^{e}\,M_1}{D}\right\} \quad (63)$$

$$C_2 = -\frac{1}{2}\left\{\frac{V_{20}^{e}\,N_2 + V_{10}^{e}\,M_2}{D}\right\} \quad (64)$$

Since in general

$$V_{20}^{e} = k\, V_{10}^{e} \angle \alpha \tag{65}$$

and assuming that V_{10}^{e}, k and α are known, one may insert (63) and (64) in (54) and (55), and thus determine I_{1s} and I_{2s} for arbitrary driving conditions.

The Input Impedance of Antennas Driven in Phase and in Phase Opposition, for Applied Voltages of Equal Magnitude.

The input impedance at the terminals of each of the two center-driven antennas is obtained from (54) and (55). (Use is made of (63) and (64).) For the in phase case,

$$V_{10}^{e} = V_{20}^{e} \tag{66}$$

and the input impedances are

$$Z_s^{I} = -\,j\,60\,\Omega_1\,D\left\{[N_1 + M_1]\left[F_{0s1} + \frac{F_{1s1}}{\Omega_1}\right] + [N_2 + M_2]\frac{P_{1s1}}{\Omega_2} - D\left[G_{0s1} + \frac{G_{1s1}}{\Omega_1} + \frac{Q_{1s1}}{\Omega_2}\right]\right\}_{z_1=0}^{-1} \tag{67}$$

$$Z_s^{II} = -\,j\,60\,\Omega_2\,D\left\{[N_2 + M_2]\left[F_{0s2} + \frac{F_{1s2}}{\Omega_2}\right] + [N_1 + M_1]\frac{P_{1s2}}{\Omega_1} - D\left[G_{0s2} + \frac{G_{1s2}}{\Omega_2} + \frac{Q_{1s2}}{\Omega_1}\right]\right\}_{z_2=0}^{-1} \tag{68}$$

Here Z_s^{I} is the input impedance of antenna (1) in the presence of antenna (2), and Z_s^{II} is the input impedance of antenna (2) in the presence of antenna (1). The voltages applied to the input terminals of the antennas are equal in amplitude and are in phase.

When the antennas are driven in phase opposition, one requires

$$V_{10}^{e} = -\,V_{20}^{e} \tag{69}$$

For this case

$$Z_a^{I} = -\,j\,60\,\Omega_1\,D\left\{[N_1 - M_1]\left[F_{0s1} + \frac{F_{1s1}}{\Omega_1}\right] - [N_2 - M_2]\frac{P_{1s1}}{\Omega_2} - D\left[G_{0s1} + \frac{G_{1s1}}{\Omega_1} - \frac{Q_{1s1}}{\Omega_2}\right]\right\}_{z_1=0}^{-1} \tag{70}$$

$$Z_a^{II} = -j\,60\,\Omega_2\,D\left\{[N_2 - M_2]\left[F_{0s2} + \frac{F_{1s2}}{\Omega_2}\right] - [N_1 - M_1]\frac{P_{1s2}}{\Omega_1} - D\left[G_{0s2} + \frac{G_{1s2}}{\Omega_2} - \frac{Q_{1s2}}{\Omega_1}\right]\right\}_{z_s=0}^{-1} \quad (71)$$

Here Z_a^I is the input impedance of antenna (1), and Z_a^{II} is the input impedance of antenna (2). The voltages applied across the input terminals are equal in amplitude, but are opposite in phase.

In the next section it will be shown that the self-impedance of each radiator, and mutual impedance, may be readily defined in terms of the four impedances Z_s^I, Z_s^{II}, Z_a^I and Z_a^{II}.

Mutual and Self-Impedance for Antennas of Unlike Dimensions.

Designating Z_{s1} and Z_{s2} the self-impedances of antennas (1) and (2), respectively, and Z_{12} the mutual impedance, one may write

$$V_{10}^e = I_{10}\,Z_{s1} + I_{20}\,Z_{12} \quad (72)$$

$$V_{20}^e = I_{20}\,Z_{s2} + I_{10}\,Z_{12} \quad (73)$$

In (72) and (73), I_{10} is the input current to antenna (1), and I_{20} is the input current to antenna (2). When the antennas are driven in phase, these currents will be primed; when driven in phase opposition the currents will be double-primed. Now by definition

$$\frac{V_{10}^e}{I'_{10}} = Z_s^I = Z_{s1} + \frac{I'_{20}}{I'_{10}}Z_{12} \quad (74)$$

$$\frac{V_{20}^e}{I'_{20}} = Z_s^{II} = Z_{s2} + \frac{I'_{10}}{I'_{20}}Z_{12} \quad (75)$$

$$\frac{V_{10}^e}{I''_{10}} = Z_a^I = Z_{s1} + \frac{I''_{20}}{I''_{10}}Z_{12} \quad (76)$$

$$\frac{V_{20}^e}{I''_{20}} = Z_a^{II} = Z_{s2} + \frac{I''_{10}}{I''_{20}}Z_{12} \quad (77)$$

For antennas driven in phase, $V_{10}^{e} = V_{20}^{e}$, hence

$$\frac{V_{10}^{e}}{Z_s^{II}} = I'_{20} \tag{78}$$

and

$$\frac{V_{10}^{e}}{Z_s^{I}} = I'_{10} \tag{79}$$

Accordingly,

$$\frac{Z_s^{I}}{Z_s^{II}} = \frac{I'_{20}}{I'_{10}} \tag{80}$$

For antennas driven in phase opposition, $V_{10}^{e} = -V_{20}^{e}$, and

$$-\frac{Z_a^{I}}{Z_a^{II}} = \frac{I''_{20}}{I''_{10}} \tag{81}$$

Using (80) and (81) with (74) – (77), it is a simple process to show that

$$Z_{s1} = \frac{Z_a^{I} Z_s^{I} (Z_a^{II} + Z_s^{II})}{Z_s^{I} Z_a^{II} + Z_s^{II} Z_a^{I}} \tag{82}$$

$$Z_{s2} = \frac{Z_a^{II} Z_s^{II} (Z_a^{I} + Z_s^{I})}{Z_s^{I} Z_a^{II} + Z_s^{II} Z_a^{I}} \tag{83}$$

$$Z_{12} = \frac{Z_a^{II} Z_s^{II} (Z_s^{I} - Z_a^{I})}{Z_s^{I} Z_a^{II} + Z_s^{II} Z_a^{I}} \tag{84}$$

For identical antennas,

$$Z_{s1} = Z_{s2} = \frac{Z_s^{I} + Z_a^{I}}{2} \tag{85}$$

$$Z_{12} = \frac{Z_s^{I} - Z_a^{I}}{2} \tag{86}$$

The expressions (85) amd (86) have been previously published. Having determined Z_{s1}, Z_{s2} and Z_{12}, an analysis may be made of two element array performance, when the individual radiators are driven in any arbitrary way, which includes the case of a driven antenna in proximity to a director or reflector (the latter being center-loaded if desired).

Parasitic Antenna Arrays.

Referring to Figure (1), let it be assumed that antenna (2) is driven, and that antenna (1) is a parasitic reflector (the input terminals, located at $z_1 = 0$, are shorted). In this case equations (72) and (73) become

$$0 = I_{10} Z_{s1} + I_{20} Z_{12} \tag{87}$$

$$V_{20}^{e} = I_{20} Z_{s2} + I_{10} Z_{12} \tag{88}$$

Solving (87) and (88) simultaneously,

$$Z_{in} = \frac{V_{20}^{e}}{I_{20}} = Z_{s2} - \frac{Z_{12}^{2}}{Z_{s1}} \tag{89}$$

(If the reflector is tuned,

$$Z_{in} = Z_{s2} - \frac{Z_{12}^{2}}{Z_{s1} + Z_L} \tag{90}$$

where Z_L is the complex impedance connected across the input terminals of the reflector.) Here Z_{in} is the driving point impedance of the array. A knowledge of this impedance not only enables one to design a matching network to secure optimum power transfer from the generator into the array, but from it the power radiated may be predicted. This is obtained from

$$P_r = I^{2}_{20} R_{in} \tag{91}$$

R_{in} is the resistive component of the driving point impedance.

In designing a two element array, consisting of driven and reflecting elements, one may choose the radii of the wires (a_1 and a_2) at random. (The analysis is expected to be quantitatively accurate only when

$$\left.\begin{aligned} a_1 &< < h_1 \\ a_2 &< < h_2 \\ \beta a_1 &< < 1 \quad \text{or} \quad \beta a_2 < < 1) \end{aligned}\right\} \tag{92}$$

This having been done, and assuming that the length $2h_1$ is known, the design problem is to ascertain:

(a). The appropriate length of the director or reflector.

(b). The spacing between elements.

In sone instances one is interested in securing an optimum forward field strength to backward field strength (called "front to back ratio"). In other applications it is desirable to maximize the field in the forward direction. In either case, the field in the equatorial plane of the array must be determined.

Now it has been demonstrated in several recent analyses[5-8] that for antennas of moderate thickness the shape of the radiation field pattern differs only slightly from that for an extremely thin antennas carrying a simple sinusoidal current. Thus it is satisfactory to assume a sinusoidal distribution of current along the antenna for computing the distant field, but the *amplitude of the input currents, together with the phase angle between them* must be determined using a more rigorous theory. It is not legitimate to employ mutual and self-impedance based on "assumed currents" for this purpose.

Using (87) in the form

$$I_{10} = -I_{20}\frac{/Z_{12}/}{/Z_{s1}/}e^{-j(\phi_{s1}-\phi_{12})} \tag{93}$$

$$\phi_{s1} = \tan^{-1}\frac{X_{s1}}{R_{s1}};\ \phi_{12} = \tan^{-1}\frac{X_{12}}{R_{12}} \tag{94}$$

a simple computation reveals that[9,10]

$$\epsilon = j\,60\,I_{20}\frac{e^{-j\beta R}}{R}\left\{\frac{1-\cos\beta h_2}{\sin\beta h_2} - \frac{/Z_{12}/}{/Z_{s1}/}\cdot\frac{1-\cos\beta h_1}{\sin\beta h_1}\cdot e^{-j(\phi_{s1}-\phi_{12}+\beta b\cos\phi)}\right\} \tag{95}$$

The following notation is used:

ϵ is the electric field in the equatorial plane of the array (this

5. Charles W. Harrison, Jr., and Ronold King, "The Radiation Field of a Symmetrical Center-Driven Antenna of Finite Cross Section," Proc. I. R. E., Vol. 31, No. 12, pp. 693-697; December, 1943.
6. Ronold King and Charles W. Harrison, Jr., "The Receiving Antenna," Proc. I. R. E., Vol. 32, No. 1, pp. 18-34; January, 1944.
7. Charles W. Harrison, Jr., and Ronold King, "The Receiving Antenna in a Plane-Polarized Field of Arbitrary Orientation," Proc. I. R. E., Vol. 32, No. 1, pp. 35-49; January, 1944.
8. Charles W. Harrison, Jr., "The Radiation Field of Long Wires, with Application to Vee Antennas," Jour. Appl. Phys., Vol. 14, No. 10, pp. 537-544; October, 1943.
9. Ronold King, "Notes on Antennas," Engineering 270, Harvard University.
10. Charles W. Harrison, Jr., "A Note on the Characteristics of the two-Antenna Array," Proc. I. R. E., Vol. 31, No. 2; February, 1943.

plane passes through the centers of the antennas, and is at right angles to their axes).

R is the distance from the point of field calculation, in the distant zone, to the point $z_2 = O$. For (95) to be valid,

$$\left.\begin{aligned} \beta R &>> 1 \\ \frac{h}{R} &<< 1 \end{aligned}\right\} \tag{96}$$

where h is the half-length of the longer antenna.

The initial line, $\phi = 0$ degrees, is b in Figure (1), with sense to the right. Thus $\phi = 0$ degrees defines the forward direction, and $\phi = 180$ degrees defines the backward direction. It is evident that the problem of designing a two element array, consisting of a driven element and parasitic director or reflector, devolves into a graphical study of (95). For this purpose, accurate values of mutual and self-impedance for antennas of unlike dimensions must be available.

NOTES.

INDEX TO NOTES.

Segregation in Babbitt.
—Metals Technology, Institute of Mining and Metallurgical Engineers, September, 1944.

Electrical Machinery on Ice Breakers.
—Motorship, December, 1944.

Kort Nozzles on Maritime Commission Tugs.
—Motorship, December, 1944.

Magnaflux Testing of Steel Castings.
—Marine Engineer, November, 1944.

Rubber Ponton Bridges—in 1846!
—Military Engineer, January, 1945.

The Salvage of the USS Oklahoma at Pearl Harbor.
—Nautical Gazette, December, 1944.

Carbide Hobs for Cutting Marine Propulsion Gears.

Electrical Machinery for use with Ship's Auxiliaries.
—The Institute of Marine Engineers, December, 1944.

Miscellanea of Interest to Naval Engineers.
Examining Tubes for Corrosion.
—Mechanical World, September, 1944.

X-ray Pictures in a Millionth of a Second.
—Westinghouse Engineer, January, 1945.

Silicon Rubber.
—General Electric Review, January, 1945.

SEGREGATION IN BABBITT.

This paper reprinted from Metals Technology was prepared by T. E. Eagan and W. R. McCrackin, Chief Metallurgist and Assistant Chief Metallurgist, respectively of the Cooper Bessemer Corporation. It was read at the New York meeting of the American Institute of Mining and Metallurgical Engineers in February, 1944.

In dealing with segregation in babbitt, and its effect on the final cast structure, which is a bearing, it is obviously impossible to cover all of the compositions manufactured. Each composition, of course, will exhibit certain specific types of segregation. However, as examples, two compositions of babbitt are presented: one a tin-base of well-known analysis and the other a lead-base, which in the past few years has found wide usage. Bearings usually are cast either statically or centrifugally; therefore the effect of these two methods on segregation is presented.

Experimental Procedure.

A slab of babbitt ½ inch thick by 5 inches wide and 17 inches long was cast, using a book mold with the long edge vertical. An A.S.T.M. grade 2 babbitt was used (3.5 per cent copper, 7.5 per cent antimony, remainder tin), to which 0.10 per cent tellurium had been added. Unfortunately, no metal without tellurium was available.

The mold to hold the babbitt was heated to approximately 300 degrees F., the temperature being judged by the babbitter. The pouring temperature of the babbitt was 875 degrees F. (470 degrees C.).

One slab was made by allowing the babbitt to cool without stirring. The other slab was stirred during the entire cooling cycle. This stirring consisted of a vigorous churning or puddling into the mold until complete solidification had taken place. Three samples were removed from these slabs. One was taken at the extreme bottom, another half way to the top, and another at the extreme top, all at the center of the width. Chemical, macroscopic and microscopic examination was made of all samples. Table 1 shows the chemical analyses obtained at the described positions in the slab. The analyses show no serious amount of gravity segregation. Microscopic examination from edge to edge of the slab showed little change in structure. From top to bottom there was a progressive coarsening of the grain size in the stirred slab but little change in the slab that was not stirred (Figure 1). No definite exhibit of segregation could be detected.

Table 1.—Chemical Analyses, A.S.T.M. Grade 2 Babbitt.
Per Cent.

Position	Not Stirred		Stirred	
	Cu	Sb	Cu	Sb
Top	3.44	7.59	3.38	7.57
Middle	3.45	7.53	3.40	7.40
Bottom	3.46	7.50	3.42	7.62
Pot Analysis	3.46	7.48	3.46	7.48

In line with our experimental study on the tin-base babbitts, we cast an almost duplicate slab using A.S.T.M. Alloy No. 15, containing 0.9 to 1.25 per cent tin, 14.75 to 15.5. per cent antimony, 0.80 to 1.25 per cent arsenic

and 0.4 per cent copper. The slab was 16 inches long and ⅜ inch thick, cast with the long side vertical. One slab was allowed to cool normally and the other was stirred continually during cooling. The pouring temperature of the babbitt was 975 degrees F. Chemical and microscopic samples were again taken at the bottom, middle and top of the slab. The chemical analyses obtained are given in Table 2. Again we find that chemical analyses show little or no segregation of the constituents; therefore we must rely on the microstructure for our study of segregation.

TABLE 2.—CHEMICAL ANALYSES, A.S.T.M. ALLOY NO. 15
PER CENT.

Position	Not Stirred			Stirred		
	As	Sb	Sn	As	Sb	Sn
Top	1.13	14.7	1.21	1.14	13.9	1.12
Middle	1.14	15.1	1.20	1.12	14.0	1.18
Bottom	1.12	14.7	1.11	1.08	14.0	1.09

The mosaic photomicrograph shown in Figure 2, taken at 50 diameters after the metal had been etched with 50 per cent aqueous HCl solution, represents the typical structure found across the thickness of the stirred and unstirred samples. The specimen used for illustration was taken from the middle of the slab. The top and bottom specimens showed approximately the same microstructure.

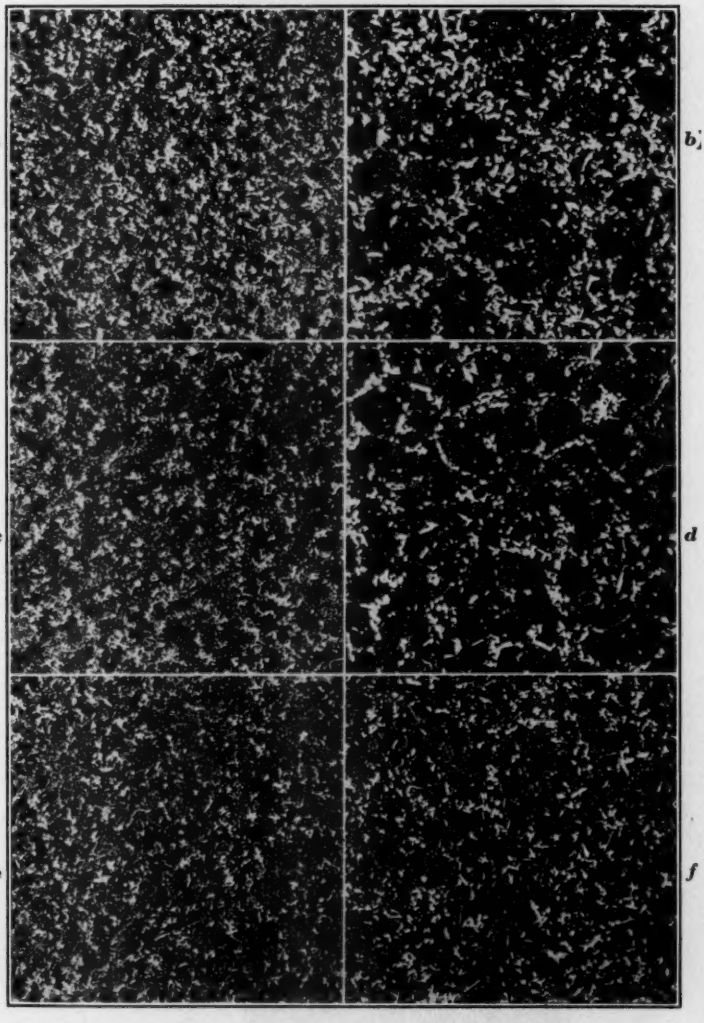
A considerable difference in microstructure can be observed. Contrary to what might be expected, the structure of the unstirred sample is much finer than that of the stirred sample. Blumenthal,* in a recent study of the lead-antimony alloys, has shown that these alloys are subject to considerable super-cooling, which no doubt would also hold for the babbitt under discussion, in that it is predominantly a lead-antimony alloy. It is believed, therefore, that this fine structure is caused by supercooling. A supercooled liquid solidifies rapidly and causes the finely divided structure. As stirring inhibits supercooling, the stirred sample shows a much coarser structure.

From the segregation standpoint, the stirred sample shows a rather uniform, although coarse, distribution of the various phases across the section. The unstirred shows a concentration of the excess constituent, which probably is an antimony-rich solid solution at the surfaces in contact with the mold; whereas, as the center is approached there are large areas where there is none of this constituent. The matrix in both cases is probably the eutectic antimony-rich and lead-rich solid solutions, with perhaps some ternary eutectic of the lead, antimony and tin. Although chemical analyses were not taken, the photomicrograph gives good evidence that segregation has taken place in the unstirred sample, which has been minimized by stirring.

CASTING OF BABBITT.

The static casting of bearings is perhaps the most widespread method of making them. They are made both in the smallest machine shops in the most unexpected places, and in the finest babbitting departments in large manufacturing concerns. With this fact in mind, certain general

* B. Blumenthal: Constitution of the Lead-antimony and Lead-antimony-silver Systems. *Trans.* A.I.M.E. (1944) 156, 240.



Not Stirred Stirred

FIGURE 1.—MICROSTRUCTURE OF STATIC-CAST TIN-BASE BEARINGS. × 150.
ETCH, $FeCl_3$ PLUS HCl IN H_2O.
3.5 per cent Cu, 25 per cent Sb, remainder Sn.

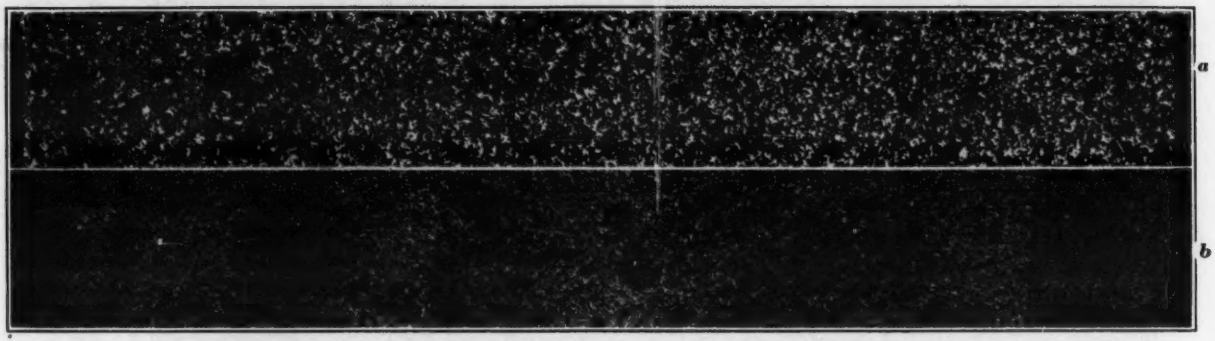


FIGURE 2.—MOSAIC PHOTOMICROGRAPH OF CROSS SECTION OF STATIC-CAST LEAD-BASE BABBITT.
15 per cent Sb, 1 per cent Sn, 1 per cent As, 0.4 per cent Cu, remainder Pb. *a*, Stirred; *b*, not stirred. Original magnification 50; reduced ⅔ in reproduction. Etched in 50 per cent HCl.

FIGURE 3. FIGURE 4.

FIGURE 3.—LEAD-BASE BABBITT CAST ONE INCH THICK. NOT STIRRED. × 150. ETCH, HCl.
15 per cent Sb, 1 per cent Sn, 1 per cent As, 0.4 per cent Cu, remainder Pb.

FIGURE 4.—LEAD-BASE BABBITT CAST ONE INCH THICK. STIRRED. × 150. ETCH, HCl.
15 per cent Sb, 1 per cent Sn, 1 per cent As, 0.4 per cent Cu, remainder Pb.

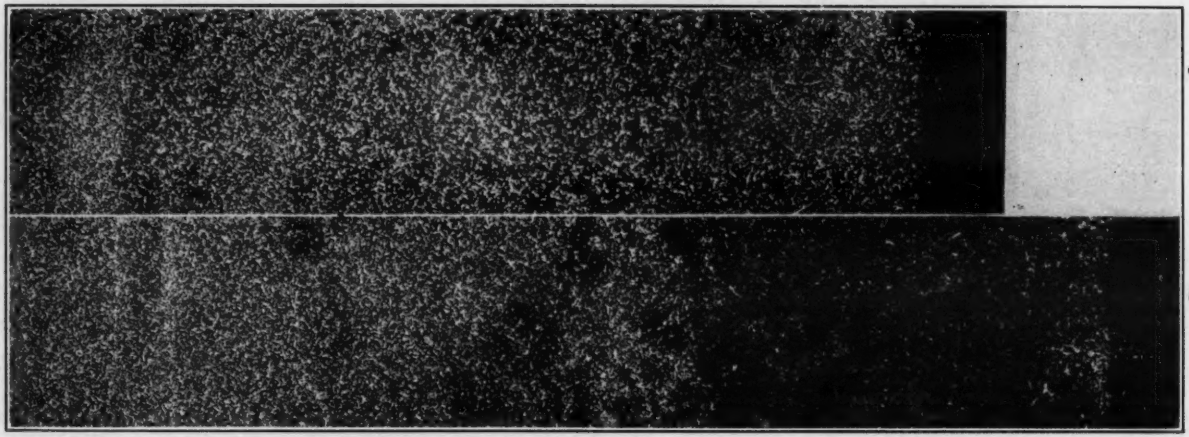


FIGURE 5.—MOSAIC PHOTOMICROGRAPH OF CROSS SECTION OF CENTRIFUGALLY CAST TIN-BASE BABBITT. STEEL BEARING SHELL TO LEFT. 3.5 per cent Cu, 7.5 per cent Sb, remainder Sn. *a*, chilled; *b*, not chilled. Original magnification 50; reduced 2/5 in reproduction. Etched in $FeCl_3$ plus HCl.

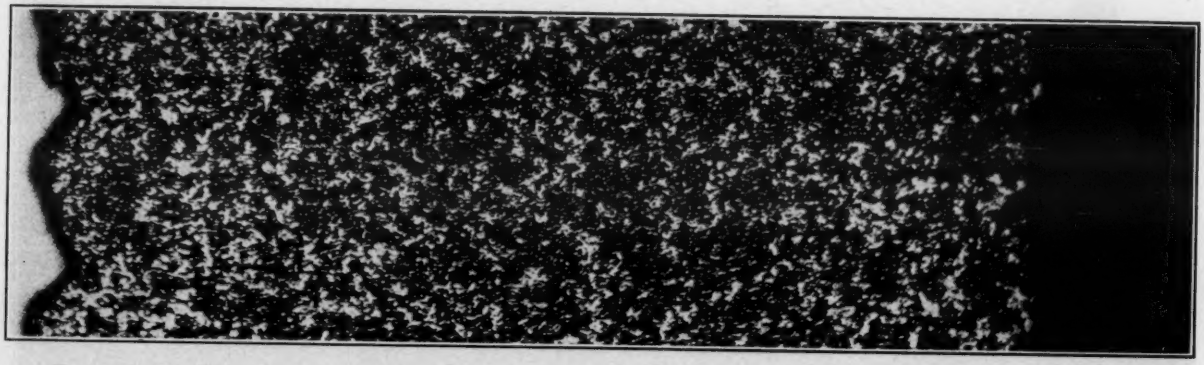


FIGURE 6.—TIN-BASE BABBITT CENTRIFUGALLY CAST AND COOLED WITH AIR-WATER SPRAY. × 50. ETCH, $FeCl_3$ PLUS HCl. Normal structure found in a properly cast bearing. 3.5 per cent Cu, 7.5 per cent Sb, remainder Sn.

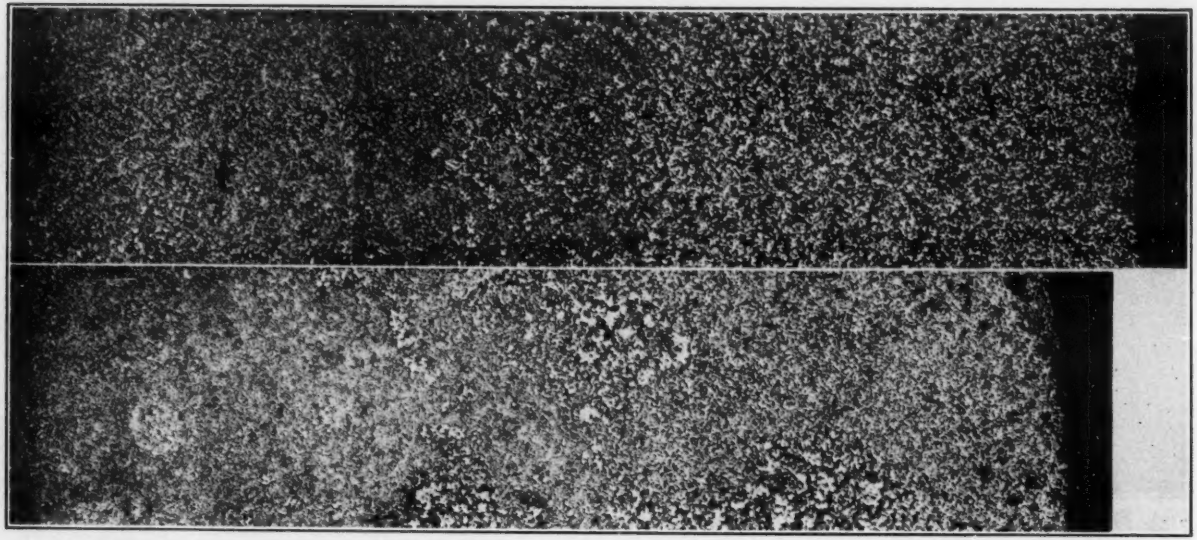


FIGURE 7.—MOSAIC PHOTOMICROGRAPH OF CROSS SECTION OF CENTRIFUGALLY CAST LEAD-BASE BABBITT. STEEL-BEARING SHELL TO LEFT. × 50. ETCH, 50 PER CENT HCl.

15 per cent Sb, 1 per cent Sn, 1 per cent AS, 0.4 per cent Cu, remainder Pb, *a*, chilled; *b*, not chilled.

FIGURE 8.—LEAD-BASE BABBITT CENTRIFUGALLY CAST. NORMAL STRUCTURE FOUND IN A PROPERLY CAST BEARING. STEEL BACKING TOWARD BOTTOM. × 50. ETCH, HCl.

15 per cent Sb, 1 per cent Sn, 1 per cent As, 0.4 per cent Cu, remainder Pb.

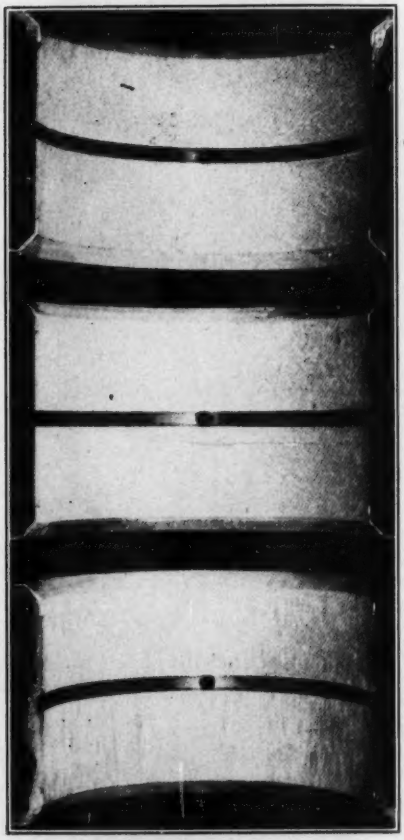


FIGURE 9.—CRYSTAL SEGREGATION IN BEARINGS MADE OF TIN-BASE BABBITT.
a. Good crystallization. *b*. Uneven Crystallization. *c*. Bad segregation.
Etched with ammonium polysulphide.

principles concerning the casting of bearings and the control of segregation are presented below.

In the first place, the casting of babbitt against a metal backing is not in any way different from the casting of any other metal in a mold. It will shrink, hence hot metal must be provided to feed it. It can cool in such a way as to cause segregation. It can be so cast that all dirt and dross is trapped in the metal, if not allowed to float out of the way. The backing can be designed, and unfortunately often is deliberately so, that no amount of care and ingenuity can effect uniform cooling. It is imperative, therefore, that due consideration be given to every principle of foundry practice and casting design. The fact that babbitt metal melts at relatively low temperatures and pours easily is no reason that these principles should be ignored. Ample information on casting design and foundry practice has been published. In this paper only the factors that effect segregation will be considered.

Effect of Cooling Rate.

Cooling rate has a great influence on the segregation obtained, therefore the major factors that control this cooling rate should be given considerable attention. These may be stated to be: (1) temperature of the jigs, fixtures and backings; (2) pouring temperature of the babbitt, (3) design of the bearing back, (4) design of the jigs and fixtures, (5) thickness of babbitt.

Temperature of Jigs, Fixtures and Backing.—The temperature of the jigs and fixtures has a profound influence on segregation and structures obtained. By properly heating these jigs to a temperature predetermined by the trial and error method of cutting samples, etching and examining them, a fairly uniform structure from top to bottom and from edge to edge can be obtained. Simple means to determine these temperatures are available today in the form of pencils of materials that have definite melting points. The temperatures may vary from 300 degrees to 600 degrees F., depending on the size of bearing, thickness of babbitt and shape of backing. We are limited to some extent as to the temperature of the backing because it is usually the temperature of the tinning bath, which in turn is limited by the oxidation temperature of the particular tinning method used. Furthermore, the jigs, fixtures and the backing should be evenly heated.

Pouring Temperature of Babbitt.—Next under consideration is the pouring temperature of the babbitt. It can readily be seen that very hot babbitt will heat the jigs and fixtures, which in turn will cause slow cooling through the solidification range; thus giving great chance for the excess constituents freezing from the liquid to move either to the top or bottom of the bearing, depending on their density and thus causing serious gravity segregation. On the other hand, babbitt poured too cold—that is, below the recommended pouring temperature—may be in such a condition that the liquidus is reached at the time of pouring and the high-melting-point constituents have already started to precipitate out of the liquid. When this metal is poured into a mold and allowed to cool, a great change of gravity concentration again takes place. The recommended pouring temperature is always the best to use, with the temperature of the jigs and fixtures varied to suit.

Design of Bearing Back.—It is with considerable trepidation that the authors attempt to criticize the design of the bearing backs. This criticism has always met with considerable resistance. It has been the practice for many years to design the backing to meet the requirements of stress and fits, no consideration being given to the fact that this backing becomes part of the mold into which the babbitt is cast.

As an example, one need only mention the usual design of a bearing cap. First, there is a semicircular cylinder, to which is attached an arch

supported by a certain number of ribs, all radiating out from the cylinder. To allow proper attaching to other members, patches are added usually to the ends of the semicircle for drilling the bolt holes. In addition to this, dovetail grooves usually are cut into the back, to give an anchor for the babbitt.

In considering this one shape of backing from the angle of segregation, the heavy ends having such a considerable mass of metal, and being cooler, chill the babbitt, then the positions where the ribs join the cylinder take the heat away from the metal, leaving that section of the cylinder between the ribs and the ends of the bearing to be the last to cool. In addition to this, the babbitt that is not directly over the dovetails is thinner than that over them, and cools faster, thus further differentials of cooling are produced. The final result usually is a badly segregated babbitt.

The answer to this has been to cast the babbitt on a separate simple cylinder of uniform cross section and to use it as an insert in the cap. The results have been a phenomenal improvement in life and load-carrying ability of the bearings. It is fully recognized that such a simple solution to the design problem cannot always be accomplished, but it is certainly not logical to ignore it completely. Therefore, bearing backs should be designed so as to have a uniform cross section. This can be done by removing as many bumps, fins, ribs, etc., as possible. Dovetails may be removed by improving the practice of cleaning and tinning the back before casting the babbitt. In the authors' plant they are being removed as fast as the drawings can be changed. This is true of cast steel, cast iron, and bronze backs. A notable improvement in life of the bearings has already been noted, as well as a considerable saving in their cost.

Finally, as has been mentioned before, the back should be designed so that proper foundry and molding practice can be accomplished. To enter into a complete discussion of this is beyond the scope of this paper.

Design of Jig and Fixtures.—The design of the jig is just as important as the design of the bearing, because together they act as the mold for the babbitt. They also should be designed to conform to the best foundry and molding practice.

Perhaps the greatest trouble experienced with jigs is that they do not seal properly, and consequently there is leakage of the babbitt. It must be remembered that as the babbitt cools below the liquidus temperature, solid compounds freeze out, changing the composition of the remaining liquid metal. If this liquid is drained away, the composition of the babbitt will be changed at the place where the leak occurs; hence, there will be a spot of composition different from that of the rest of the bearing, which is segregation. To try to stop these leaks by chilling with wet rags or other means causes cooling differentials, which also causes segregation.

Jigs should be designed to give as uniform a cooling rate as possible. They should be heavy enough to avoid warping. Cooling should start at the bottom and proceed to the top. Cooling speeds can largely be controlled by a proper choice of the metal thickness used.

Thickness of Babbitt.—The thickness of the babbitt has a profound effect on the cooling rate. A very thick babbitt will cool slowly, thus causing considerable segregation. A very thin babbitt will chill so fast that air and gas are trapped in the metal, causing blowholes. There is, therefore, a median of thickness that will give a proper cooling rate. If thick babbitt must be used, the jigs and fixtures should be designed to allow water cooling. As it is possible to control cooling rate to a great extent by the methods outlined, segregation caused by cooling rate can be controlled.

Effect of Stirring Babbitt during Freezing.

The importance of stirring the babbitt during freezing cannot be emphasized too strongly. If allowed to cool without stirring, tin-base babbitts will produce myriads of small blowholes. Stirring stops the formation of these blowholes, and apparently is the only way to avoid them. The reason these holes are formed in the tin-base babbitt is not clear to the authors. It was thought that entrapped air was the cause, but experiments with pouring in such a way as to avoid the trapping of air did not stop their formation.

When the backs have uneven sections, the stirring action keeps hot liquid metal moving over the sections that are subject to chilling, thus helping to distribute the phase freezing out over a large area, and allowing a more uniform cooling rate. Stirring also reduces the amount of supercooling. It also breaks up the long columner crystals and allows the more desirable equiaxial crystals to form.

In lead-base babbitt, tests now underway seem to indicate that both structures, stirred and unstirred, give equally good life. They have not, however, proceeded far enough to give a conclusive answer. The stirred structure is the one favored by the authors because:

1. The unstirred babbitt usually is full of small blowholes or shrink cavities. These are entirely hidden in the illustration because the matrix is so dark and the subsequent reduction for reproduction in the paper blends them into the matrix.

2. The very fine structure, as shown in the lead-base babbitt and believed to be caused by super-cooling, is definitely concentrated at the outer edges, which is not desirable when we consider that subsequnt machining will remove this metal from one side.

3. In thick babbitt sections the stirring breaks up the lamellae of the eutectic as they are formed from the liquid, giving a much more uniform structure. Figure 3 shows the structure found in a one-inch section of babbitt, not stirred. Figure 4 shows the same section thickness, stirred. The massive eutectic structure shown in the unstirred sample has been broken up by the mechanical action of stirring during the time of its formation in cooling.

Addition of Small Amounts of Metal.

The addition of small amounts of metal, rather foreign to the composition of the babbitt itself, which act apparently to control crystal size, also help to control segregation. The addition of 0.10 per cent tellurium* to the tin-base metals controls the crystal size. There may be others that have not come to the attention of the authors. Apparently these metals act as inoculants, which control the amount of supercooling. They form nuclei from which crystallization starts. In profusion, these nuclei give a better chance for equiaxial crystals to form. In the tin-base babbitt the tellurium also tends to suppress the formation of the cubic SnSb crystals.

Effect of Method of Casting.

Static cast bearings are usually used for relatively low loads. By using the same metals and centrifugally casting the babbitt into a metal backing of uniform cross section, and using very thin layers of babbitt, phenomenal load-carrying qualities have been established. The ease of handling and making centrifugal cast bearings has led to a development of this process, consequently, many thousands of them are produced daily throughout the country.

The centrifugal casting of babbitt against a shell of uniform cross section eliminates many of the segregation hazards experienced in the

* Patented by Cleveland Graphite Bronze Company.

static casting of bearings. It introduces a number of others that pertain to this method of casting. In addition to the normal forces that cause segregation, there is the fact that the centrifugal force will throw the heavier material toward the outside and force the light material to the inside. As all these babbitts freeze through a range of temperature, this centrifugal force becomes a major item in causing segregation. Because of this, we have chosen to deal with this method separately, for the sake of simplicity.

As examples, the A.S.T.M. grade 2 babbitt for the tin-base material, and grade 15 for the lead-base material of the same analysis as used for the static cast bearings were centrifugally cast into shells 7¼ inches in diameter. In each case one shell was allowed to spin without accelerated cooling until the babbitt was solid; the other was chilled. The chilling of the tin-base babbitt was accomplished with an air-water spray, and of the lead-base babbitt by a very large, flat stream of water. An attempt was made to cast all specimens of the same thickness, 1/16 inch of babbitt. This thickness was considerably more than is normally used. The speed used was that previously established for the diameter of the shell used; namely, 410 Rpm. The pouring temperature of the tin-base babbitt was 840 degrees F. and of the lead-base babbitt, 975 degrees F.

These cast shells were then placed in a lathe and turnings were taken from the first, third and fifth 1/16 inch of babbitt thickness for analysis, A sample was cut from the bearing and examined microscopically for segregation.

The chemical analyses obtained for the tin-base babbitt are given in Table 3, and the mosaic microstructure from the steel shell through the babbitt thickness at 50 diameters is shown in Figure 5.

TABLE 3.—CHEMICAL ANALYSES OF CENTRIFUGALLY CAST BEARINGS OF TIN-BASE BABBITT.

PER CENT.

Position	Not Chilled		Chilled	
	Cu	Sb	Cu	Sb
Inside	1.22	7.78	2.65	7.83
Halfway through	3.61	7.63	2.97	7.43
Outside	5.85	7.19	4.63	7.23
Pot analysis	3.45	7.48		

Both the photomicrograph and the chemical analysis show that there is a great amount of segregation of the copper-tin compound toward the outside diameter of the shell, and a concentration of the antimony toward the inside diameter. Chilling in this particular case has helped to prevent the segregation of these constituents, but in the case illustrated it did not completely accomplish its mission. It must be remembered, however, that more than the normal thickness of babbitt was used in this test. By using a normal thickness of babbitt and proper chilling, a very uniform structure from the outside diameter to the inside diameter can be developed, as is shown in Figure 6.

The chemical analyses obtained from the lead-base babbitt are given in Table 4. The mosaic microstructure is shown in Figure 7.

In the lead-base babbitt, there is a segregation of the antimony, tin and arsenic to the inside of the bearing when centrifugally cast. The cooling rate and the speed of spinning have a profound influence on the amount of

segregation obtained. A properly spun and chilled structure is illustrated in Figure 8. The normal machining of bearings removes approximately one half the thickness of babbitt poured. In highly segregated bearings such as are illustrated, this machining removes a high percentage of the compounds (antimony, tin and arsenic) that have been added to give strength and hardness and to act as wear resisters in the bearing.

TABLE 4.—CHEMICAL ANALYSES OF LEAD-BASE CENTRIFUGALLY CAST BEARING.

PER CENT.

Position	Not Chilled			Chilled		
	Sb	Sn	As	Sb	Sn	As
Inside	16.50	1.51	1.08	17.20	1.38	1.61
Halfway through	14.82	1.41	1.01	17.37	1.13	1.27
Outside	11.40	0.91	0.52	12.48	0.98	0.56
Pot analysis	14.95	1.25	1.01			

SEGREGATION IN CRYSTAL SIZE AND ORIENTATION.

Besides the segregation of the various constituents in the babbitt metal, there is a tendency for the metal to show a segregation in crystal size and orientation. Figure 9 shows the macrostructure obtained in three different bearings cast of tin-base babbitt. The bottom and middle bearings were cast from the same pot of babbitt, the only difference being that certain holes in the air-water spray used in cooling were cut off. The top bearing was cast of babbitt of the same analysis with the addition of 0.10 per cent tellurium. Long, columnar crystals may be seen in the lower bearing. The junctions of these crystals are definite points of weakness in the bearing and often are the sources of premature failure. The middle bearings shows most of the long columnar grains eliminated, but they vary in size from bottom to top. The top bearing shows very fine grains, very evenly distributed.

The bearing of lead-base babbitt used for illustration in this paper does not seem to show this tendency to form long columnar crystals. At least the authors have not been able to detect them. This may be because they know of no macro etchant that will show them.

This may not be considered as true segregation, but it is included here to demonstrate that such a condition or orientation of crystals can exist. Our experience has been that service failures of bearings can be attributed to such conditions. The failure follows the junction of the two forms of crystals.

CONTROL IN CENTRIFUGALLY CAST BEARINGS.

Control of segregation in centrifugally cast bearings is not easy to accomplish, but it is being done daily with success. Certain steps must be followed rather meticulously to produce unsegregated babbitt; as outlined below:

1. Use backings with uniform cross section. Thin cross sections are greatly preferable to heavy ones.
2. Use the fewest revolutions per minute that will hold the metal against the shell to allow proper bonding. This varies with the type of babbitt and the diameter of the shell.

3. Pour only sufficient metal into the bearing to allow proper cleaning up in machining. This varies with the metal, as some materials give rougher surfaces than others.
4. Use as low a casting temperature as possible. The recommended temperature usually suffices. Guessing of this temperature is to be deplored.
5. Cool the metal to solid as quickly as possible after casting. The speed of cooling must be varied with the type of babbitt used. Some babbitts will break away from their bond if cooled too quickly.
6. Cooling should be uniform across the length of the bearing.
7. The use of babbitt with an inoculant is to be preferred.

ELECTRICAL MACHINERY ON ICE BREAKERS.

This article describing the Coast Guard's new ice breakers, reprinted from the December 1944 issue of Motorship, was prepared by James A. Wasmund, Marine Engineer of Westinghouse Electric and Manufacturing Company.

The recent commissioning of the first of four ice breakers of the "Wind" class brings to the U. S. Coast Guard fleet an extremely unusual and useful type of vessel. Everything that has been learned from years of extensive research and study of ice breaking has been incorporated in the construction and propulsion of the ship.

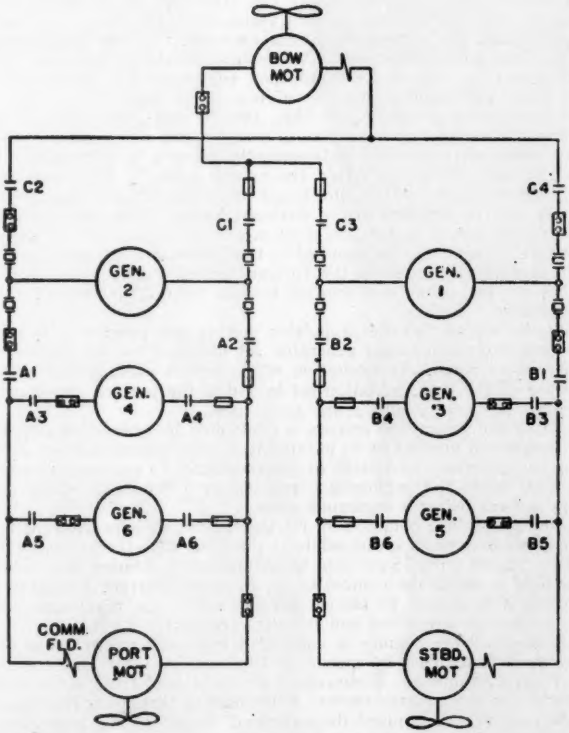
A bow propeller driven by a 3300 Shp. electric motor creates a wave ahead of the vessel that helps break the ice. Water tight bulkheads separate engine rooms so flooding can knock out only one at a time. Six Diesel generators supply power to two stern and one forward propellers. Propulsion power is controlled by the number of generators used simultaneously. Engine speed is regulated by pneumatic control of the governor.

The double hulls of these ships are of all-welded construction, specially designed to withstand the crushing force of Arctic ice. The beam is extremely wide with respect to the length and the bottom is rounded. In appearance the ice breakers give the impression of a small battleship, the effect being heightened by the considerable armament carried as anti-aircraft and anti-submarine protection. The bow has the typical ice breaker lines, while the stern is notched out in a shallow "V" so that in cases of necessity the bow of a following ship may be inserted in this notch and the combined power of the two vessels used for propulsive effort.

One unique feature of these vessels is the installation of a propeller in the bow in addition to the two stern propellers. When the vessel is free running in open water, the bow propeller may be allowed to run free or may be locked by means of a shaft break. Under ice breaking conditions the normal direction of rotation of the bow propeller opposes the motion of the ship and produces a bow wave ahead of the vessel, which aids in breaking the ice and carrying the broken pieces from the path of the vessel.

Propulsion power is obtained from six Diesel-generators, each being a 1375-Kw., 810-Rpm., 900-volt, direct-current generator driven by a Fairbanks Morse Diesel engine. These generators are direct connected to the Diesel engines and are located in pairs in three engine rooms separated by water tight bulkheads. The flooding of an engine room will result in the loss of only those machines in that room. The generators are completely enclosed and are suction-ventilated by means of ship's ventilating ducts connected to flanged openings in the commutator end enclosure.

The two stern motors are each rated 5000 Shp., 105-145 Rpm., 900-volts, and are enclosed, with surface type, water-cooled heat exchangers and



Generator main circuits for the three motors.

force-ventilated by means of motor-driven axial flow fans. Due to limited space for the installation of ventilating air ducts, the naval architect originated a novel method of recirculating the motor cooling air. A bulkhead is bolted to a flange around the after end of the motor, thus dividing the motor room into a forward and after compartment. The motor ventilating fan is mounted in the dividing bulkhead.

Air is taken from the forward compartment and forced into the after compartment under pressure. Since the after end of the motor is open, the air passes through the windings absorbing the heat loss and then passes through the water-cooled heat exchanger before being exhausted into the forward compartment. Watertight bulkheads separate the two motor rooms as well as the motor and engine rooms. Flooding of one motor room will result in the loss of one motor only.

The bow motor is rated 3300 Shp., 140-210 Rpm., 900 volts. The construction and ventilation is similar to that for the stern motors.

Each motor is controlled independently from a motor control board, located on the platform level of the motor room, or from one of three control stands located in the pilot house or on the bridge wings.

Power may be supplied to the starboard motor from one, two or three starboard generators and to the port motor from one, two or three port generators. Power may be supplied to the bow motor from either or both of the generators located in the forward engine room. Generator set-up switches on the propulsion control boards permit the desired selection of generators.

Excitation current to the propulsion motors and generators is provided by a local excitation motor-generator set mounted on the platform level in each motor room. An excitation set-up switch provides for the emergency use of the bow excitation set by either the port or starboard shaft as desired, but not by both at the same time.

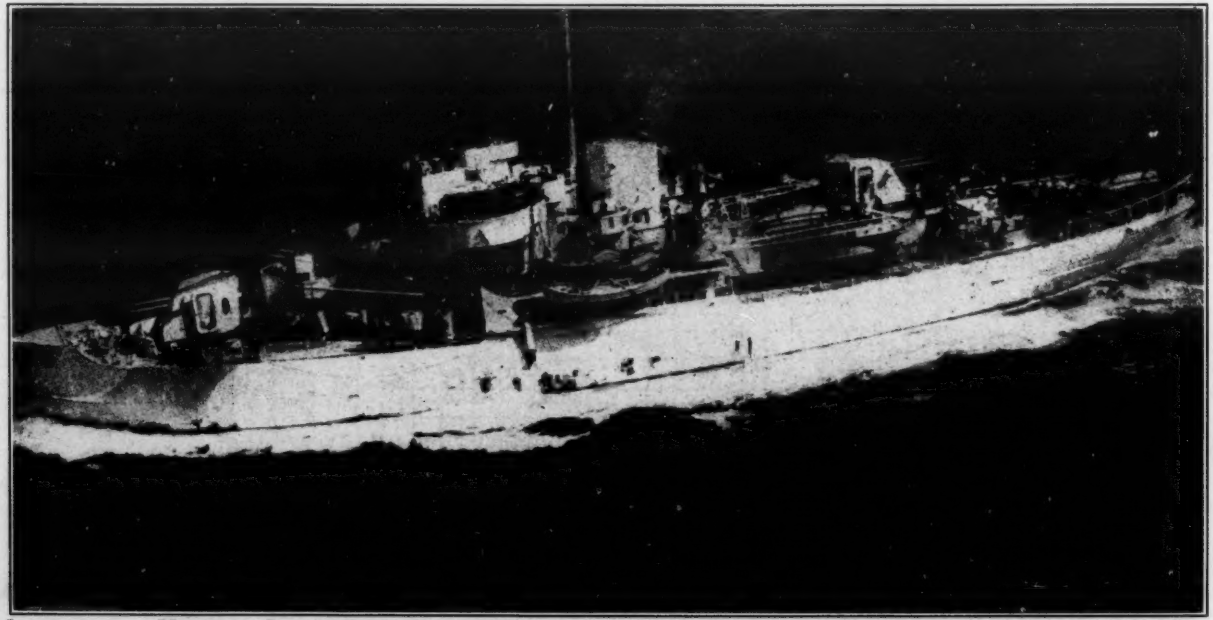
Speed of the propulsion motors is controlled by connecting one, two or three propulsion generators in parallel to a motor armature and gradually raising the generator excitation to approximately 75 per cent of maximum excitation, while the engines are running at a minimum speed and the motors are excited at a minimum value.

Higher speeds are obtained by raising the engine speed gradually from minimum to maximum speed, while at the same time the generator excitation is increased from 75 per cent to normal value. During this period, the motor field is under the control of an automatic current regulator, which will cause the motors to absorb approximately the maximum available engine output at any speed and loading condition.

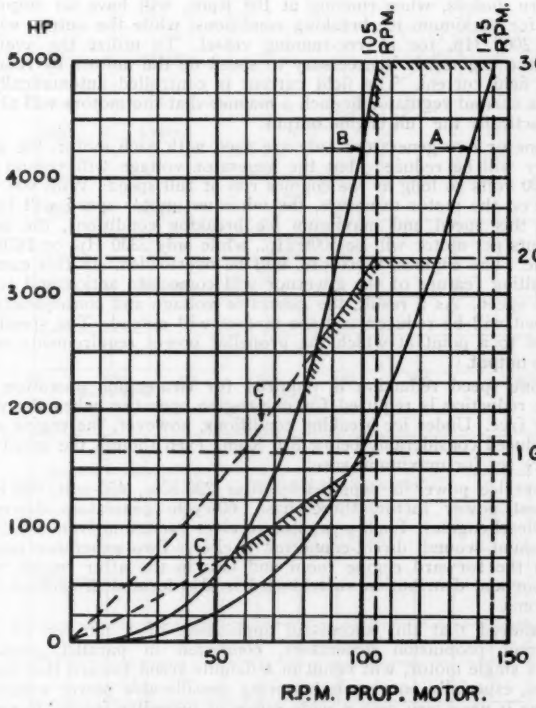
The speed of the engines is controlled from the motor room or pilot house speed controllers by means of Westinghouse Air Brake Co. pneumatic control equipment. Compressed air is obtained from air compressors in each of the three motor rooms. After passing through a reducing valve, the low pressure air is piped through small copper tubing to master speed control transmitters on the speed controllers.

The transmitters actually are pressure regulators which are connected to engine governor actuators through magnetically operated shut-off valves. By means of the pressure regulators, the pressure of the air supplied to the actuators can be regulated between zero and 60 pounds per square inch. The actual pressure is determined by the position of the regulator operating levers, which are positioned by means of cams on the speed controller shafts. Several actuators may be controlled by means of one pressure regulator, and the speed of the corresponding engines will be regulated simultaneously to the same value.

Rotary transfer valves are provided to assign control to the motor room or pilot house master transmitter. Magnetic transfer valves are mounted on each of the forward engines. The function of the valves is to connect the actuators to the stern control, when the engines furnish power



LOOKING LIKE A MINIATURE BATTLESHIP, ONE OF THE COAST GUARD'S NEW ICE BREAKERS OF THE "WIND" CLASS HAS HER TRIAL RUN THESE SHIPS ARE DIESEL-ELECTRIC DRIVEN AND HAVE SIX DIESEL-GENERATORS FOR PROPULSION POWER.



Propeller power requirements: A — For a free-running vessel; B — During maximum ice-breaking conditions; C— Generator output at reduced speeds.

to the stern propellers, or to the bow control devices, when the engines furnish power to the bow propeller.

The power required to drive a propeller varies approximately with the third power of the Rpm. for a free-running vessel. However, the power requirements will increase sharply if the speed of the vessel is retarded by ice breaking or towing. Assuming that the propeller Rpm. remains constant, the power requirements during ice breaking will show an increase of up to 100 per cent or more of the power required for free running.

.The stern motors, when running at 105 Rpm., will have an output of 5000 Hp. for maximum ice breaking conditions, while the output will be less than 2000 Hp. for a free-running vessel. To utilize the available power of the engines, it is necessary to speed up the motors by reducing the shunt field current. The field current is controlled automatically by means of a current regulator in such a manner that the motors will always absorb practically the full engine output.

When one or two generators only are used with each motor, the available power will be reduced; but the generator voltage will remain constant at 900 volts so long as the engines run at full speed. With 900 volts impressed on the motor armature, the minimum motor speed will be 105 Rpm. At this speed and maximum ice breaking conditions, the power requirements per motor will be 5000 Hp., while only 3330 Hp. or 1670 Hp. is available. The engines, therefore, will be overloaded. In this case the torque limiting feature of the governor will come into action and reduce the engine speed. As a result, the generator voltage and consequently the motor speed will be reduced and the motors will unload. The speed will be reduced to a point at which the propeller power requirements equals the engine output.

No engine speed reduction is required for two-engine operation, and very little reduction is required for one-engine operation when the vessel is running free. Under ice breaking conditions, however, the engine speed will be reduced considerably below 810 Rpm., even though the speed controllers are set for maximum speed.

Ship's service power is supplied by four 220-Kw., 450-volt, 900-Rpm., 80 per cent power factor, three-phase, 60-cycle generators driven by 300-Hp. Diesel engines. Each generator receives excitation from a 4.2-Kw., 120-volt, shunt wound, direct-connected exciter. Two generator sets are located in the forward engine room and two in the after engine room. A generator and distribution switchboard is also located in each of these engine rooms.

It is believed that this successful application of a number of large direct-current propulsion generators, connected in parallel, supplying power to a single motor, will result in a definite trend toward this type of installation, especially on vessels requiring considerable power where full horsepower is necessary over a wide range of propeller speeds, in preference to the series connection of low voltage high current generators which has been used in the past.

KORT NOZZLES ON MARITIME COMMISSION TUGS.

This article by M. M. Lachowski, Naval Architect, Dravo Corporation is reprinted from Motorship, December 1944.

In the October 1944 issue of Motorship there appeared a report on the activity and performance of the ocean-going V4-M-A1 type tugs built for the U. S. Maritime Commission.

The performance of these tugs is indeed remarkable. Their range of activity includes New Guinea, Alaska, Bermuda, Panama Canal, etc. They

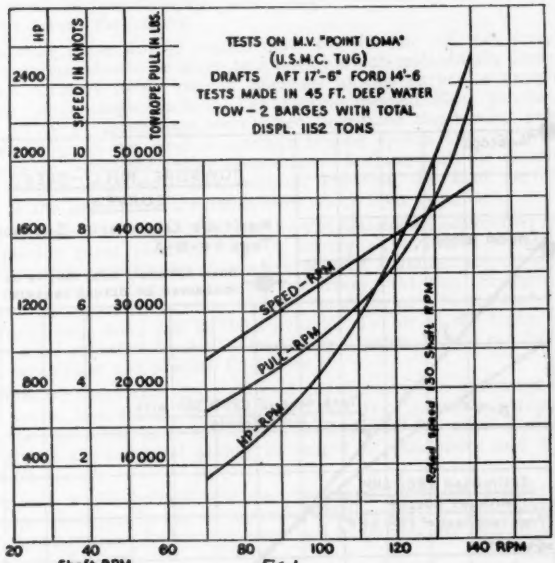

TESTS ON M.V. "POINT LOMA"
(U.S.M.C. TUG)
DRAFTS AFT 17'-6" FORD 14'-6
TESTS MADE IN 45 FT. DEEP WATER
TOW – 2 BARGES WITH TOTAL
DISPL. 1152 TONS
HP
SPEED IN KNOTS
TOWROPE PULL IN LBS.
2400
2000
1600
1200
800
400
10
8
6
4
2
50 000
40 000
30 000
20 000
10 000
SPEED – RPM
PULL – RPM
HP – RPM
Rated speed 130 Shaft RPM
20
40
60
80
100
120
140 RPM
Shaft RPM

Fig. 1

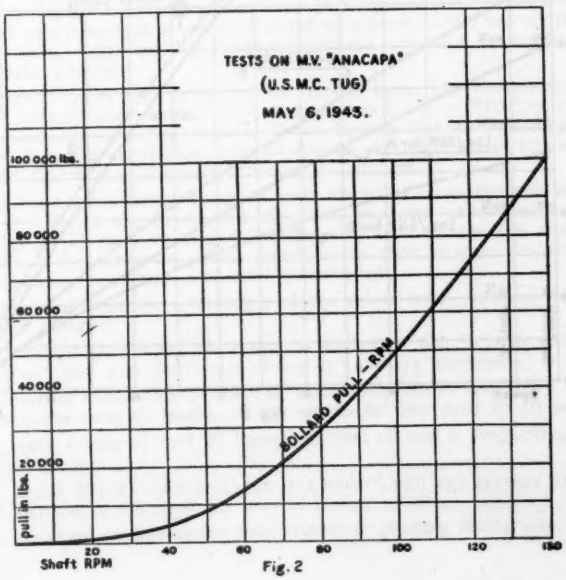

TESTS ON M.V. "ANACAPA"
(U.S.M.C. TUG)
MAY 6, 1943.
100 000 lbs.
80 000
60 000
40 000
20 000
pull in lbs.
BOLLARD PULL – RPM
20
40
60
80
100
120
130
Shaft RPM

Fig. 2

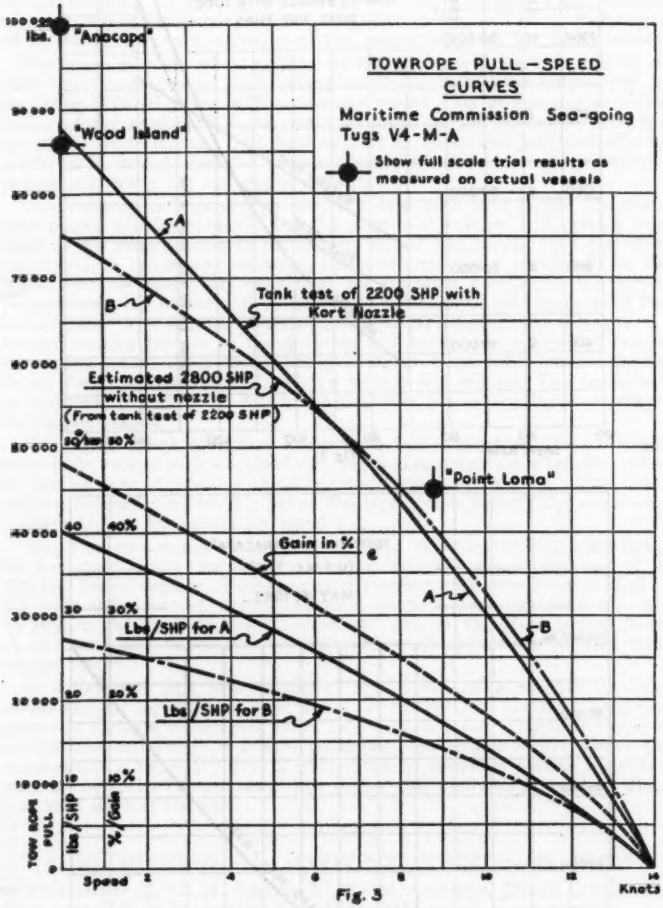

TOWROPE PULL – SPEED CURVES
Maritime Commission Sea-going Tugs V4-M-A
Show full scale trial results as measured on actual vessels
"Anacapa"
"Wood Island"
"Point Loma"
A
B
Tank test of 2200 SHP with Kort Nozzle
Estimated 2800 SHP without nozzle
(From tank test of 2200 SHP)
Gain in %
Lbs/SHP for A
Lbs/SHP for B
lbs.
Tow Rope Pull
lbs/SHP
% Gain
Speed
Knots

Fig. 3

have towed barges, disabled cargo ships, combat vessels and floating drydocks across the oceans.

In saluting these sturdy, rugged craft for the fine job they have done, due recognition should be given to a device which undoubtedly contributed as much or more to the overall efficiency of this particular design, than did any other single factor. The Dravo-designed Kort nozzles, with which all 49 of these tugs were fitted, increased the towing power by approximately 24 per cent at average towing speeds and, by reason of this increase, permitted design economies in keeping with the material and supply situation at that time, without lowering the final performance curve of the tugs below the range desired by their designers.

The preliminary design developed by the Maritime Commission required a propulsion plant of 2800 Shp. A survey of available Diesel engine manufacturing capacity for this power showed a limited source of supply, with poor prospects of satisfactory delivery. At this juncture Dravo Corporation suggested an innovation in the shape of a Kort nozzle. Extensive model tests were run at the David W. Taylor Model basin, and the results were reported by A. J. Dawson in a paper before the Society of Naval Architects and Marine Engineers.

Results of these tank tests showed conclusively the advantages of the Kort nozzle installation and indicated that the horsepower required to drive the hull could be reduced from 2800 to 2200 for equal performance, thus giving a substantial saving in weight of machinery and fuel consumption.

The pull at the bollard test was measured as 88,000 pounds for the 2200-Hp. Kort nozzle tug as against 75,600 pounds for the 2800-Hp. tug without the nozzle. Reduced to unit pull in pounds per Shp. it showed a gain of about 48 per cent.

The results of tests on actual vessels in the Great Lakes are shown in Figures 1 & 2. A towline pull of over 54,000 pounds was attained with a tow of two barges at a speed of about nine knots in the test of the tug *Point Loma*, while the tug *Anacapa* produced a bollard or standing pull of 100,000 pounds.

Figure 3 gives the results of the model basin experiments together with estimated performance of the tug equipped with a 2800-Shp. propulsion plant without a Kort nozzle. It can be seen that the performance of the Kort nozzle installation is at all speeds (except the free run speed), greater than that of the open propeller installation.

For the normal towing range of from six to 10 knots, the gain is about 31 per cent at six knots and about 17 per cent at 10 knots or an average of 24 per cent. Points representing some of the full scale trial results as measured on actual vessels show that in some instances the anticipated performance was actually exceeded.

These are, then, the advantages of the actual tugs compared with the original design:

1. Reduced purchasing price due to saving of 600 Shp. in propulsion machinery and a proportionate saving in auxiliary machinery.

2. Smaller initial cost of the hull since reduction in machinery weights allowed the over-all length of the tug to be decreased by 10 per cent.

3. Daily saving of over 20 barrels of fuel oil and a proportionate lube oil saving.

4. About 48 per cent increase in unit bollard pull and average of 24 per cent increase in unit pull for normal towing speeds.

5. Increased seaworthiness with respect to pitching in sea way.

MAGNAFLUX TESTING OF STEEL CASTINGS.

Procedure and practice referred to shipbuilding and Marine Engineering requirements.

This article is reprinted from the Marine Engineer, November, 1944.

The wide use of magnetic powder and radiographic methods of inspection render necessary a true appreciation of their limitations and a certain expertness in interpretation. Technical literature on radiographic methods is profuse, both in this country and abroad; but the opposite is the case in regard to the magnetic powder principle. For that reason, the information contained in a paper entitled "Conditioning of Steel Castings to Standards of Quality," read before the American Foundrymen's Association, in April, 1944, by Mr. Paul Ffield, is of practical value, particularly in that it is based on the practice of the shipbuilding division of the Bethlehem Steel Company. The following notes are taken from Mr. Ffield's paper.

The two principal non-destructive tests for steel castings in general use today are the magnetic powder inspection (Magnaflux) and radiographic inspection. Each method has its particular field of application, and neither should be considered as a substitute for the other, although they may be complementary under some conditions.

In marine work, the U. S. Navy has set up five grades of radiographically inspected castings, as shown in the accompanying table.

CLASSIFICATION OF CASTINGS FOR APPLICATION OF RADIOGRAPHIC STANDARDS

Class	*Casting*
1.—High-pressure valves and fittings (wall thickness less than 1 inch).	Superheater fittings.
	Boiler stop valves.
	Machinery castings subject to fatigue or impact stresses (wall thickness less than ½ inch).
2.—High-pressure turbine casings.	Steam chests.
	Turbine throttle valves.
	High-pressure valves and fittings (wall thickness 1 inch or greater).
	Low-pressure valves (wall thickness less than 1 inch).
	Machinery castings (wall thickness ½ inch or greater).
3.—Low-pressure turbine casings.	High-pressure exhaust casings.
	Low-pressure end of high-pressure turbine.
	Low-pressure valves (wall thickness 1 inch or greater).
	Machinery castings not subjected to steam pressure.
4.—Hull castings less than 3 inches in thickness—subjected to high service stresses.	
	Machinery castings not subjected to impact stresses or vibration.
5.—Hull castings 3 inches or more in thickness and subject to high service stresses.	

These classification grades are successively less rigid. For instance, a specific defect might be unacceptable for Class 1, border-line for Class 2, and acceptable for Class 3. Here is a clear-cut example of the customer specifying the grade of quality, and the foundryman can appreciate his liabilities by studying the pertinent radiographic standards before he bids on a contract. When no such standardized grading is available, the designing engineer must make a study of both the casting and the possible defects. The first step is to make a stress analysis of the casting to

determine the magnitude, type, and direction of the principal stresses. When this is done, it is possible to evaluate the various types of defects and pick out their undesirable characteristics.

For instance, radiographic quality can be dispensed with in those sections of the casting which might be termed non-structural because the actual working stresses are low. In areas subjected to high tensile stresses, an elongated defect which lies transverse to the direction of stress must be viewed with suspicion, whereas the same defect may be acceptable if its major axis is parallel to the direction of stress. However, if the stresses are compressive, the reverse well may be true. Again, if the defect is of the type that it may create a notch effect, it may be particularly serious in sections subject to dynamic loading, especially if the notch is transverse to the direction of principal dynamic stress.

The U. S. Navy and other organizations have been specifying radiographic quality for certain castings for about eight years, and there is now a sufficient background of experience so that allowance can be made for the extra work and time which the premium quality demands. There has been practically nothing published about magnetic powder inspection which is applicable to heavy castings of the type used in ship construction, and the limitations of this method of inspection must be fully appreciated before making it one of the acceptance tests for large steel castings.

Basically, the magnetic powder test is a qualitative, not a quantitative test. It will search out and find a discontinuity, but usually other means must be found to evaluate the magnetic powder indication. In its simplest application, it is extremely useful as a substitute for acid etching of cavities during conditioning of a casting. For sound repair welds, it is necessary to remove all traces of cracks or other significant defects. Frequent magnetic powder check during excavation will insure this with a minimum loss of time and with the removal of a minimum amount of metal. Experience shows that it is more reliable than acid etching when excavating cracks and, with an experienced operator, just as reliable when excavating shrinkage or sand. As soon as the use of magnetic powder inspection is extended to function as a means of finding defects, then care must be exercised before applying the test.

The magnetic powder method of inspection requires that the piece be critically magnetized so that the disturbance in the magnetic field created by a defect will be sufficient to cause the paramagnetic powder to adhere to the surface of the casting. Obviously, the technique of magnetization is one of the factors determining the effectiveness of this test. There are several ways of magnetizing the piece to be tested, but the principal method used for the inspection of large steel castings is to pass a current through the piece by either the "prod method" or the "all-over method." In the former case, electrical contact with the casting is made by means of two closely spaced prods, connected to a suitable source of current. Only the section of the casting between the prods is magnetized. In the all-over method, electrical contact is made at each end and the whole casting is magnetized. Obviously, the latter method requires a much greater supply of current. Welding machines and wet batteries generally are used for the prod method, whereas generators or rectifiers of several-thousand-amperes capacity are necessary for the all-over method.

Electric Current Requirements.

The amount of current required to critically magnetize the area to be inspected depends on the mass and shape of the piece, light sections responding much more readily to the magnetizing current than heavy sections. This is particularly true when the all-over method is used for large castings of complex shape. The flow of current will not be evenly distributed throughout the cross section of the casting, but there will be a tendency for more current to flow through preferred sections, resulting

in variations in the flux density. The effectiveness of the magnetic powder test depends on sufficient current reaching the area to be tested, so that this area becomes critically magnetized. The significance of this statement is that when inspecting large castings of complex shape by the all-over method, more and more indications will be developed as the magnetizing current is increased.

There are other variables associated with the method of magnetization which also must be considered when applying the magnetic powder test. For instance, where it is desired to bring out subsurface defects, the greater the depth below the surface, the greater the current required to resolve the subsurface discontinuity. Likwise, the more rounded or spherical defects will require more current for delineation than the sharp or crack-like variety. Furthermore, the piece to be tested may be magnetized during or prior to the application of the powder, at the discretion of the operator.

Test Specifications.

To obtain uniform results when magnetic powder inspection is specified, either the exact method of magnetization or a specific flux density in the area to be inspected should be specified. Unless these are clearly defined, the foundryman would be well-advised not to bid on such an order because of the uncertainty of his contractural obligations. It is not always appreciated that the magnetizing technique is important. Some specifications are so loosely worded that they do not even specifically require that the piece be magnetized. The following is quoted from such a specification covering the inspection of welded piping: "Radiographic and other tests; all welded piping exceeding 1½ inches in diameter shall be tested either by radiography or by using a paramagnetic powder dusted over the area to make sure that there are no cracks or other defects. Should the quality of the joint be questioned by an inspector—the weld shall be cut out and the joint rewelded." Obviously, the effectiveness of such an inspection test would depend on how conscientious the operator was in critically magnetizing the piece.

Interpretation of Tests.

The interpretation of the magnetic powder indications, like the interpretation of radiographic films, requires considerable experience. However, the magnetic powder test differs from radiography in that it is not practicable to accurately gauge the depth (or sometimes the subsurface magnitude) of the defect. In radiography, an operator with some experience usually is able to gauge the depth of the defect and to appraise its subsurface extent when he examines the radiograph. When necessary, he can always resort to the simple expedient of making two or more exposures of the same area from different angles, permitting a full appraisal of subsurface defects by mensuration or by pereoscopy. Unfortunately, the evaluation of magnetic powder indications is not always as straightforward. While the prime function of the magnetic powder test is to search out and delineate the defect, its subsurface extent can be estimated by noting the magnetic powder pattern and the amount of "build up" of powder with different magnetizing techniques. Positive appraisal can be made only by exploration or by supplementing the magnetic powder test with radiographic inspection of the questionable areas.

It is generally accepted that magnetic powder inspection is more reliable on machined or otherwise smooth surfaces, but it is not practicable or necessary to grind or smooth the surface of a casting before inspection. Many false indications will occur at surface blemishes, such as rough fins, snagging chisel marks, surface sand, etc. The most rapid method of showing the insignificance of these indications to the inexperienced will

be a local visual inspection of the area, or possibly by grinding the area smooth and repeating the test.

Detection of Cracks.

The magnetic powder test is ideal for locating cracks or tears which extend to the surface. When the direction of the magnetic field is critically oriented, a strong indication will be developed. Visual examination of the area, after removal of the indication, usually will show the presence of the crack. Subsurface cracks also may be shown by wide and fuzzy indications. Depending on their magnitude, they can be shown at considerable depths below the surface, with the proper magnetizing technique, but the indications may be weak and sparse. Such indications can be mistaken for minor shrinkage, or even sand, and differentiation is difficult without further exploration, such as by radiography.

There is one type of crack readily found by the magnetic powder test which calls for considerable engineering judgment in its interpretation. The sensitivity of the test will disclose the presence of "tight" cracks at or near the surface of almost any large steel casting. These cracks are not visible to the unaided eye after removal of the magnetic powder indication. They are not something new and, undoubtedly, always have been present in large steel castings, but they have been only recently revealed when magnetic powder inspection was used. They are prevalent in areas which are subject to cooling stresses, such as fillets or sharp changes in sections.

Considerable judgment in the interpretation of these tight cracks is required because they appear to be alarming in their length and stress-concentrating ability. No engineer likes to make the decision that any crack is harmless. It often is easy to evaluate shrinkage or porosity and state that it is insignificant, but with a crack there is always the possibility that it may propagate in service. If the engineer makes the usual arbitrary decision that all cracks shown by magnetic powder indications must be removed, then the job of conditioning such a casting may become laborious and will, of course, result in delays and increased cost.

Regarding the depth of these "tight" cracks, the most reliable yardstick is the length and continuity of the indication. Experience shows that the depth of a surface crack is somewhat a function of its continuous length, and usually is less than 50 per cent of the latter. Thus, if a crack is 4 inches long, it is unlikely that it will exceed 2 inches in depth. If it appears to be, say, 9 inches long, but close examination shows it to be a series of short cracks, the longest of which is 3 inches, the average depth of the 9 inch long indication is likely to be about 1½ inches.

Complementary Testing.

A useful way of using magnetic powder inspection is to make it complement to radiographic inspection. For example, if in the radiographic inspection of a series of identical castings it is found that some are defective in the same area, a standard often can be created for this location. Areas which have been radiographed are also inspected by magnetic powder. The powder pattern is compared with the radiographic image and the relationship between each method of test established as a standard for the area under consideration. Subsequent castings then may be magnetically inspected instead of radiographed in this area, at a considerable saving in time. An advantage of this form of inspection is that it enables the operator to gain experience in the evaluation of magnetic powder indications.

In the case of castings which are being radiographically inspected, the foundry can save considerable time and unnecessary work if the surface

defects are located by an "all-over" magnetic powder inspection. The time consumed for such a test would be only a few minutes from start to finish, and the inspecting personnel is assured that most of the surface defects and many subsurface discontinuities have been located. However, this test should not be made a part of the acceptance test unless everyone concerned is thoroughly familiar with the significance of the indications which are likely to be found.

RUBBER PONTON BRIDGES—IN 1846!

This article by Dr. Ivor D. Spencer Assistant Professor of History, The Citadel is reprinted from The Military Engineer, January, 1945.

The time is 1846. General Zachary Taylor is invading Mexico through the Rio Grande basin, and General Winfield Scott, at Washington, is preparing for a grand assault upon Vera Cruz and perhaps upon Mexico City. At New York and in and around Boston, the infant rubber industry is keeping the rollers of its trim machines turning apace. Its technicians are preparing novel war equipment—*rubber pontons*—carefully designed for the speedy bridging of rivers or for use as rafts for ferrying. This is no imaginary picture. It is *blitzkrieg,* 1846 style!

In the Mexican War of 1846-1848, the United States Army had regular trains of rubber pontons manufactured. This material was sent into the field and accompanied our attacking armies. After the war it remained in use for some years to come, as our standard military bridging equipment.

Early History.

The ponton is, of course, a very ancient bit of military equipment, employed by the Persians and the Romans among others. Even the familiar wooden bateau type dates from the seventeenth century.[1] The waterproofing of fabrics with rubber is not new, either. Grants of monopoly for manufacturing of this sort were made by Charles I. Not until the first part of the nineteenth century, however, did the general use of rubber become practical through the improvements of the celebrated James Macintosh and others. By the end of the eighteen-twenties an approach to our problem of a rubber boat had in fact been made, because an Arctic expedition of Captain John Franklin had been fitted out with rubberized life preservers and boat coverings—a prophetic step. The all-important vulcanizing process of Charles Goodyear, discovered in 1839, put an already growing industry firmly upon its feet. By 1845, clothing, roofing, "air beds," and the rubber tire were among the diverse objects of the trade.[2]

Trials of rubber pontons came well before Goodyear's epochal finding. As early as 1834, two Americans[3] built a fishing boat "consisting of two cylinders lashed together, made of duck, coated with india-rubber dissolved in spirits of turpentine." Some years later what were described as trouting boats, perhaps of this design, were advertised for sale at Boston. The first military effort came in 1836, when Captain John Lane, United States Army, threw a 350-foot experimental bridge over the deep and rapid Tallapoosa River in Alabama. Sixteen pontons were used. Captain Lane in that year also constructed a forty-ponton span across the Chattahoochee at Fort Mitchell. In both trials, the floats were primitive single-cylinder affairs made of duck coated with ordinary india-rubber. This year of development also saw the first ponton of three attached cylinders, made by William H. Harlow of Roxbury, Massachusetts;[4] it was presumably far more stable than Lane's floats.

The 1836 experiments, while probably approved by high army authorities, could look to no immediate adoption in practice, for at this time the

army had no funds for regular ponton trains. As a matter of fact, an over-thrifty congress allowed no funds for a Corps of Engineers, either.[5]

Reauthorization of Engineer Corps and Military Use of Rubber Pontons.

When in 1845 and 1846 military crises loomed with Great Britain and Mexico over the Oregon and Texas questions, President Polk and Secretary of War William L. Marcy[6] requested authorization for an engineering corps as part of a generally enlarged military establishment.

At this time, also, General Zachary Taylor, commanding the army sent into Texas, wrote (on August 26, 1845) to ask for "a moderate supply" of pontons and ponton wagons.[7] Some days after this, one G. H. Crosman, a quartermaster at Taylor's camp at Corpus Christi, in writing of Taylor's desire for speed in the matter, said significantly: "It is believed this equipage can be soonest obtained of the India rubber company at Boston." Speaking but little of the general advantages to be had by using rubber, Crosman argued that the lightness of the equipment would enable it to be forwarded speedily.[8] The request was not honored, however, because no congressional authorization existed for this purpose and the strict-constructionist Polk administration was unwilling to divert other funds.[9]

The government's request for a corps of "sappers, miners, and pontoniers" was still resting in the lap of Congress when, on the evening of May 9, 1846, news arrived of the outbreak of fighting in the disputed area between the Nueces and the Rio Grande, the commencement of the Mexican War of 1846-1848.[10] And down in the Rio Grande country on that same evening, coincidence had it, "Old Zach" Taylor, for want of a ponton train was deprived of a golden chance to cross the great river and destroy the Mexican Army at Matamoras.[11] Spurred into action by the shedding of American blood, Congress now authorized the establishment of an engineer company along lines specified by the Chief of Engineers. Included in this grant were moneys for bridging equipment.[12]

Manufacture of the equipment was now begun in all haste. The work was performed partly in New York, but mainly in the Boston area, then the country's chief rubber manufacturing district. The first task was to prepare a train of forty pontons for Taylor. Harlow's 1836 design was probably followed fairly closely for Taylor's train as well as for the slightly smaller train for Scott, which was made ready in twenty working days after the receipt of the order.[13] In the manufacture of a third train, destined for demonstration purposes at West Point, a number of innovations was made. These changes were the work of the officers of the engineering corps, particularly of Captain George W. Cullum. The most notable of the alterations was the division of the cylinders into three compartments to render them less vulnerable. In all three of the trains, the new vulcanized rubber was employed.[14]

In the ensuing campaigns of the war, the Corps of Engineers, rushed to the front after intensive training at West Point, acquitted itself splendidly. It is unpleasant, on the other hand, to have to admit that no major use was found for the pontons. By the time that they reached Mexico, the only rivers our forces were still obliged to cross were comparatively narrow ones, and it proved possible to pass these rivers by their own bridges, which, in general, had not been destroyed by the enemy.[15]

Design and Organization of Rubber Ponton Train.

The experiment in canvas-and-rubber pontons was fortunate in at least one respect, however. It had in Captain Cullum an able and loving historian. George W. Cullum (1809-1892) is known to West Point graduates as the founder of the *Biographical Register of the Officers and*

Graduates of that institution and as the donor of the hall named for him there.[16] Yet it is a more unique claim to distinction that he supervised "almost exclusively" this pioneering venture with a new military tool, and that, at the order of Colonel Totten,[17] he became the recorder of the effort. His book on the subject, the lucid, scientific little *Description of a System of Military Bridges, with India-Rubber Pontons,*[18] is an admirable work. While technically an official report (planned, by the way, as a textbook for army use) and written with caution and good sense, its pages are still enlivened with the enthusiasm with which the devoted Cullum infused them.

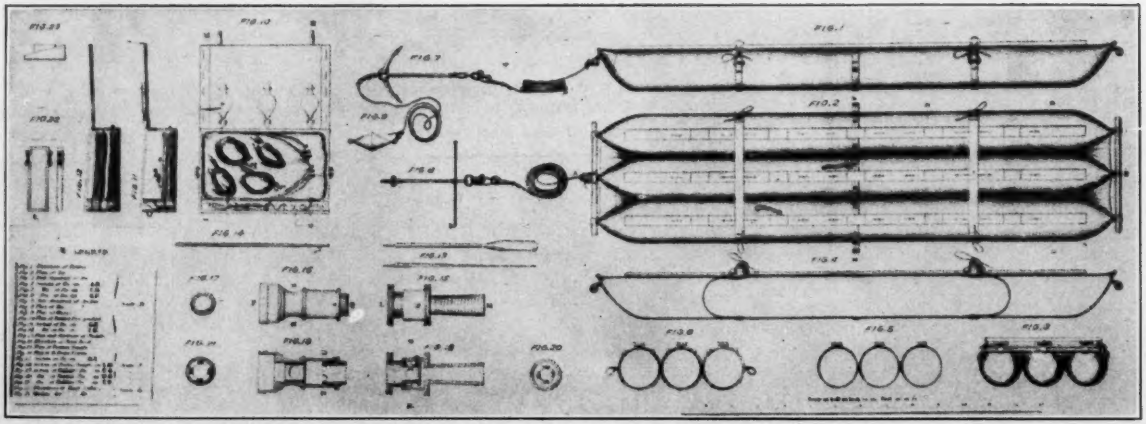
The chief unit in Cullum's "system," the three-cylinder ponton float, is indicated in the first of the illustrations accompanying this article, reproduced from his book. It is described by the author as follows:

> The pontons are made of double india-rubber cloth, and consist each of three tangent cylinders, peaked at both extremities like the ends of a canoe, which are firmly united together, by two strong india-rubber ligaments, along their lines of contact, and widening into a connecting web towards the ends, in proportion as these diminish—the whole thus forming a single boat twenty feet long and five feet broad. . . .
> Each cylinder was divided into three compartments, all with well-designed inflating nozzles. The central compartment upheld the whole middle of the roadway, but it was thought far enough inside to be secure from injury, "especially from shot," except in rare instances. Inflation, in these pre-compressed-air days, was by means of hand bellows.

The plan for a typical train, according to subsequent discussion, was for thirty such units, which when combined with the trestles used at either end would make thirty-three bays totalling 200 yards. This distance was thought the maximum likely in North America (outside of the United States, that is) in the area then regarded as likely to see fighting by our armies. As to dimensions, the pontons were anchored 8 feet apart from center to center, while the bridge roadway was 11 feet 8½ inches wide between the side rails. Each regular wagon of the train carried one deflated ponton, packed in a special box to protect it from injury, and also the balks, chesses, and side rails suitable for one complete bay. It was also provided that by means of special bands attached to all of the pontons, two or more of the floats might be fastened together to make rafts suitable for ferrying. Here, in embryo, was the present concept which we have of the rubber boat.[19]

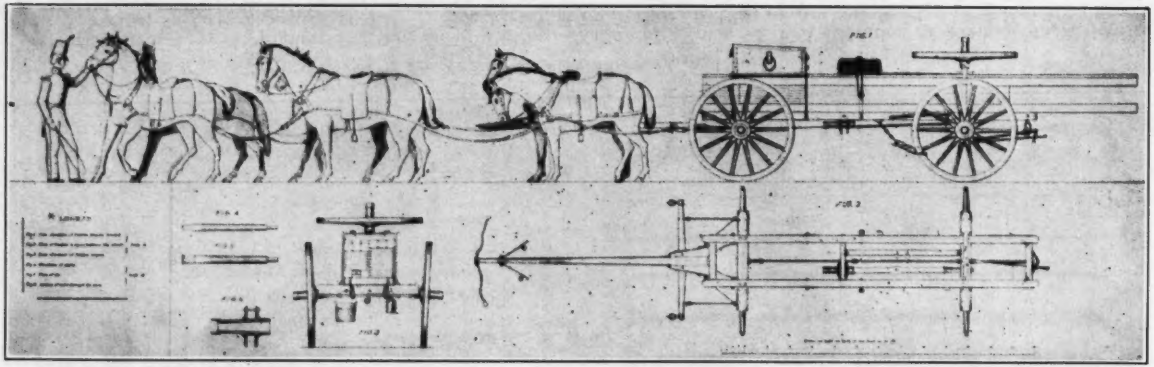
Of much interest is the care that was shown for maintenance and repair. Small holes were to be patched temporarily by using little pieces of rubber, which were to be stuffed in and tied in place by a knot in the cord fastened in the center of the patch. Sergeants of the corps carried supplies of these patches in their pockets. Permanent repairs were to be made by means of a special field kit of rubber-manufacturers' tools. Each kit held bits of rubber cloth, rubber cement, camphine, brushes, seam rollers, knives, and stitchers.[20]

The trains built in 1846 were the standard equipment of our army for the next dozen years.[21] Their obvious advantages were in compactness and lightness. Cullum pointed out that, while the French bateau bridge of nearly 200 meters took seventy-four carriages, ours of about the same length required only thirty-five and the loads were lighter. If the full bridge flooring of the reserve train were carried in the advance train, so as to permit the passage of siege artillery, the train would still be lighter than the French advance-guard train, which did not allow the use of such guns.[22] The potential merits of the American plan were recognized in France, for in 1849 and in 1860 the Seine and the Rhine saw three Gallic experiments with rubber military bridges.[23]



DETAILS OF RUBBER PONTONS OF 1846.

Transcription of Legend: Figures 1, Elevation of Ponton; 2, Plan of Ponton; 3, End Elevation of Ponton; 4, Section on AB; 5, Section on CD; 6, Section on EF; 7, Side Elevation of Anchor; 8, Plan of Anchor; 9, Plan of Buoy; 10, Plan of Ponton Box packed; 11, Section on GH; 12, Section on IK; 13, Plan and Elevation of Paddle; 14, Elevation of Boat hook; 15, Plan of Ponton Nozzle; 16, Plan of Bellows Nozzle; 17, Section on RS; 18, Section on LM; 19, Section on PQ; 20, Section on NO; 21, Section on TU; 22, Elevations of Rack Collar; 23, Wedges for Rack Collar.



DETAILS OF THE PONTON WAGON.

Transcription of Legend: Figures 1, Side elevation of Ponton wagon, loaded; 2, Plan of Ponton wagon without the wheels; 3, Rear elevation ofponton wagon; 4, Elevation of spoke; 5, Plan of spoke; 6, Elevation of nave through the axis.

RUBBER PONTON BRIDGE EQUIPMENT OF TODAY.

RAFT ASSEMBLY.

DETAILS OF THE TREADWAY BRIDGE.

TANKS TESTING THE RUBBER PONTON BRIDGE. Signal Corps

Abandonment for Other Types.

In the very sentence in which Cullum praised the "compactness, lightness and facility of manoeuvre and transportation" of his floats, he judiciously added that it required "the test of long experience to determine whether they may not also have great defects."[24] The test of long experience in actual wartime use was never supplied, but in the dozen years that followed, one defect did become evident. The sulphur used to vulcanize the rubber generated sulphuric acid, which in turn destroyed the canvas of the pontons. Thus, by 1858 or earlier, the floats made in 1846 had become quite unserviceable. A logical answer to this problem was that the cost was scarcely so prohibitive as to block periodic replacement, but perhaps the authorities felt that Congress would not take so generous a view. Another fault, according to a report made years after, was that the extreme elasticity of the pontons gave "a rocking and oscillating motion so violent as to render it unsafe for the passage of animals." The greatest weakness lay in the susceptibility of the floats to damage, either by simple chafing, as when launched from a gravelly beach, or, more critically, by rifle fire. As a report argued, a single sharpshooter on the enemy's side of the stream might destroy the pontons "as fast as they are launched." This statement seems to have been something of an exaggeration, but the point was a serious one.

In view of the expected or actually experienced defects, Cullum and his superiors alike were convinced that the rubber pontons must be abandoned. In the autumn of 1858, therefore, a number of European ponton types were tested and trails were made with a new corrugated-iron boat. The upshot was the choice of the French wooden bateau for the reserve train and of a canvas-covered ponton for the advance. The wooden bateau thus became the real stand-by, the traditional tool of our army, to remain such until partly replaced by other means in the present war.[25]

Thus ended the experiment of 1846.[26] It was a trial made noteworthy by the fact that it utilized a material, namely vulcanized rubber, that an infant industry had developed only six or seven years before. The striking character of this course was naturally emphasized by the failure of rubber pontons to be adopted permanently until nearly a century later. That the experiment was no fly-by-night one has been shown already. The effort was made in all seriousness, after initial tryouts of somewhat similar floats a few years before, and while the new equipment was not really tested in war, it was used in practice maneuvers for over a dozen years. In consideration of the relatively limited advancement of our industrial technology at that time, the failure was probably inevitable, regardless of any further improvements that might then have been attempted. In any case, the episode was a creditable instance of that mechanical ingenuity of which Americans were already so proud one hundred years ago.

References.

[1]George W. Cullum, Description of a system of military bridges with india-rubber pontons. Prepared for the use of the United States army, New York, 1849, p. 10; also his Systems of military bridges in use by the United States army, those adopted by the great European powers, and such as are employed in British India. With directions for the preservation, destruction, and reestablishment of bridges, New York, 1863, p. 170.

[2]India Rubber World, 1936, reprint, New York Public Library, pp. 1-8; Boston Courier, Dec. 3, 1842, cited in R. F. Wolf, India Rubber Man. The Story of Charles Goodyear, Caldwell, Idaho, 1939, p. 126.

[3]Gulielmus B. Millard and James Brown.

[4]Cullum, Description of a system, p. 11, and Courier, loc. cit.

[5]In the wars of 1775 and 1812, a Corps of Engineers had existed, but in 1821 the unit had been abolished by an act for reducing the Army. In the intervening years, a number of officers had been available as an "engineering staff," but, as Col. Joseph G. Totten, the Chief Engineer, put it in 1845, these men were like "theoretical mariners" because of the lack of troops with which to practice their operations. Secretaries of War and the House and Senate Military committees had often pleaded for the re-creation of a Corps, and the Army Staff naturally favored the project unanimously. Bills to effect this had passed the Senate, but had gone no further. Report of Chief Engineer to Secretary of War, Oct. 31, 1845, House Executive Documents No. 2, 29th cong., 1st sess., pp. 277-288; report of the Commanding General to the Secretary of War, Nov. 29, 1845, ibid., p. 210.

[6]The present writer is preparing a life of Marcy.

[7]Report of Secretary of War, Nov. 29, 1845, ibid., pp. 193-210, 277-288; message of Polk to Senate, Mar. 24, 1846, James Buchanan, Works (Philadelphia and London, 1908-1911), vol. VI, 428-430.

[8]Letter to Col. H. Stanton, Assistant Quartermaster General, Sept. 4, 1845, House Executive Document No. 60, 30th cong., 1st sess., pp. 638-639.

[9]Cf. endorsements on the above letter, ibid., pp. 639-640.

[10]Diary of James K. Polk, Chicago Historical Society's Collections, ed. by M. M. Quaife, Chicago, 1910, vol. I, p. 386.

[11]Taylor to the Adjutant General, May 18, 1846, Document No. 60, cited above, pp. 297-298. Such, at least, was Taylor's claim. Actually, a greater obstacle lay in his own inertia; J. H. Smith, The War with Mexico, 2 vols., New York, 1919, I, 175-177.

[12]The enlisted personnel were to number one hundred, and these were to be joined to the engineer officers already in the army to form an engineering corps. In peacetime the unit would aid in the program of instruction at West Point and some of the men might be assigned to aid in and oversee work on costal fortifications. Not until 1861 was there more than the single company. Chapter 21, May 15, 1846, p. 369 and footnote, in John F. Callan, the Military laws of the United States . . . to the year 1863, Philadelphia, 1863.

[13]The pontons were made by S. T. Armstrong of New York City and Cheever and McBurney of Boston; the wagons and harnesses were also made in or near Boston. (Cullum, Description of a system, p. 9 and notes.) A letter of T. S. Jesup, Quartermaster General, to Capt. D. H. Vinton, July 25, 1846, indicates that the pontons for Taylor came from Boston. (Document No. 60, p. 609.)

[14]Description of a system, p. 11.

[15]For the training of the men and their excellent work in Mexico, cf. reports of Totten, Nov. 10, 1846, Nov. 18, 1847, Nov. 18, 1848, Senate Exec. Docs. No. 1, 29th cong., 1st sess., p. 137 and 30th cong., 1st sess., pp. 627-628, and House Exec. Doc. No. 1, 30th cong., 2nd sess., pp. 279-281. Cf. also J. H. Smith, op. cit., passim.

[16]Dictionary of American Biography, New York, 1928-1937; Cullum's autobiographical notice, in his Biographical Register, cited above, vol. I, pp. 535-537 (Boston and New York, 1891 ed.). Cullum wrote many books and was also active in scientific and philanthropic work.

[17]Description of a system, p. 6; cf. also his autobiographical sketch, cited above.

[18]Published by the Engineer Department in 1849, and also privately, in 1849, and printed in his Systems of Military Bridges (cited above) in 1863.

[19]Description of a system, pp. 13-47, passim, and pp. 83, 88. The description of the process of manufacture of the pontons, which Cullum wrote with the aid of experts of the industry, gives a fine glimpse of contemporary rubber-working methods. See especially pp. 15-18.

[20]Ibid., pp. 19-20, 31-32, 39-40, 46, 47.

[51]Professional papers of the Corps of Engineers, U. S. Army, No. 33. Ponton Manual, Washington, 1915, p. 5.

[52]Description of a system, pp. 10-11.

[53]Systems of military bridges (1863), p. 24, footnote, citing the work of a Captain Meurdra. Russian authorities used rubber in combination with a number of other materials, as part of a compound for waterproofing their bateaux. (Ibid., pp. 162-163).

[54]Description of a system, pp. 10-11.

[55]In the Civil War, the wooden pontons did excellent work. Across the lower Chickahominy, for example, there was thrown a bridge about 2,000 feet long, which accommodated nearly the entire Army of the Potomac. When such pontons were badly mauled in rough water at Harpers Ferry, they were repaired with wood from bread boxes and thus bore out the claims of their backers as to ease of maintenance. (Professional papers, cited above, pp. 5-10; Cullum, Systems of military bridges, pp. 150-151, 170-172.)

[56]Another experiment that was suggested and perhaps tried was with rubber sacks for protecting food and other stores from damage by the weather. This was urged by Major General Thomas S. Jesup, the Quartermaster General, in a letter to Secretary Marcy from the camp at the Brazos Santiago, January 1, 1847; Document No. 60, p. 569.

THE SALVAGE OF THE *U.S.S. OKLAHOMA* AT PEARL HARBOR.

This paper was presented by Capt. F. N. Whitaker, U.S.N., at the annual meeting of the Society of Naval Architects and Marine Engineers, November, 1944, and is reprinted from The Nautical Gazette, December, 1944.

The Salvage of the *U.S.S. Oklahoma* at Pearl Harbor, created an unusual amount of interest and was appreciated by a most attentive and serious audience. Captain Whitaker's presentation of the paper was excellent and he spoke, as he most certainly has the right to do, with complete authority and knowledge of the subject which commanded the utmost attention by his audience. Captain Whitaker's interesting paper contained in part—During the Japanese attack at Pearl Harbor on December 7, 1941, the *U.S.S. Oklahoma* capsized rapidly 151 degrees 30 minutes to port (away from shore), due to extensive torpedo damage on the port side. About 410 men were lost inside the ship, and most of their bodies were recovered, but not identified, during the salvage operations. However, during the day and night following the loss of the ship, more than thirty men were rescued alive through holes cut in the bottom of the hull by members of the ship's company and by Navy Yard personnel.

The *Oklahoma* was one of the older battleships completed in 1916 and later modernized in 1929 by the addition of blisters and other improvements. Its over-all length is 583 feet and maximum beam 107 feet 11 inches, including blisters, and the longitudinal spacing of transverse frames is 4 feet.

After capsizing, the vessel was resting in about 40 feet of water with starboard bilge upward and above water, and the normally upper port side embedded about 20 to 25 feet into the mud. At mean low water, the centerline keel at the bow was about 2½ feet below the surface and at the after end of the knuckle, just forward of the rudder, about 1 foot above water. Amidships the centerline keel was about 230 feet from the line of the outboard faces of the quays parallel to which the ship had been secured previously when afloat, outboard of another battleship that was against the quays. In the capsized position the stern of the *Oklahoma* was about 40 feet farther away from the quay line than the bow.

Analyses of test borings showed that the after two-thirds of the ship was resting in relatively solid soil whereas the forward portion was essentially floating in soft mud, the depth of which down to solid material increased toward and beyond the bow.

Exterior diving investigations, confirmed later by interior diving, disclosed structural damage along the port side above the mud line from about frame 35 to frame 100, a distance of 260 feet; and, from the positions of the topmast houses, it was judged that the tripod masts and other superstructure were broken or badly bent and embedded in the mud on the offshore side of the ship.

The decision to salvage the vessel was based on a desire to remove the obstruction from the harbor and on the possibility of utilizing the ship or material therefrom in the war effort. In view of the position and condition of the ship and of the depth of water available in the harbor, it was considered that the only feasible method of salvage was that of righting and refloating the vessel in its capsized location and then of towing it to one of the drydocks in the Navy Yard nearby.

Preparations for Righting.

As indicated, the accomplishment of the installations and arrangements discussed in the preceding sections proceeded concurrently up to the beginning of righting operations.

After installation and connection, all winches were operated under no load for "wearing-in" purposes; and an attempt was made to calibrate two winches by the use of weights. However, it was found that the results varied somewhat from winch to winch.

After all tackles had been reeved, they were outhauled one at a time and connected to the 3-inch pendants previously attached to the headframes after the installation of the back-stay cables. The hauling ends of the tackles were then attached to the winch drum, and a tension of 5000 pounds applied to the 1-inch wire on each half of the drum, thus raising the outer blocks of the tackles about 10 feet above water. Tensions in the hauling parts of the 1-inch wire rope tackles were measured at this time and during righting operations by portable strain gauges. The pressure required for a given offset in the wire was read from the gauge dial and the tensile load on the wire was then obtained from a calibration curve applicable to that gauge. The back-stay cables had been previously set by visual observation of tautness to as nearly equal tensions as practicable by adjusting the nuts on the bridge socket bolts at the upper ends.

A communication system of the inter-office type was installed to give two-way communication between Central Control and the various observation stations; and personnel was detailed in three sections to man all stations on a 24-hour basis during righting operations. The contractor provided personnel to perform operations under his cognizance on a two-shift basis.

The relative locations of the various observation and control stations are indicated in Figure 1. The details and purpose of each of these stations, other than the air control barges previously discussed, are indicated by the following descriptive information:

(1) *Power House and Winches.* The temporary power house was located back of the middle of the winch foundations on shore just under the Central Control Station. The observations taken were the volts and amperes input to each winch motor; and, at each winch, the effective diameter of each winch drum as varied by the number of layers of wire on the drum.

(2) *Position Station, Forward* (Figures 2 and 3). On shore near the shore line opposite frame 29 on the ship in a direction parallel to the righting tackles.

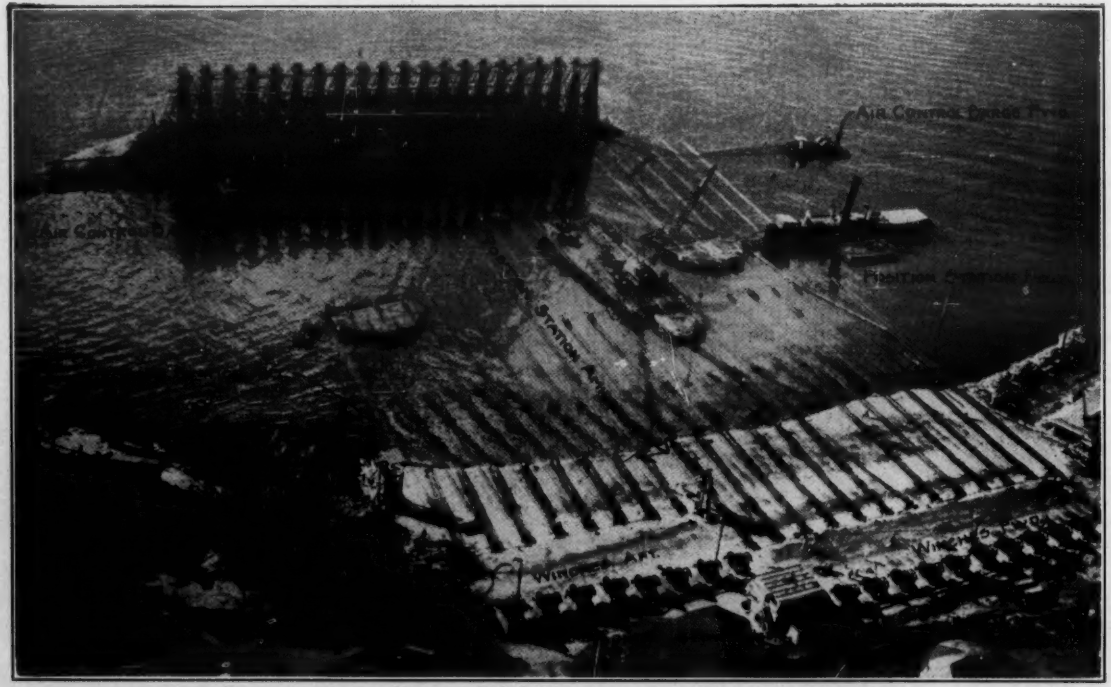


FIGURE 1.—AERIAL VIEW OF U.S.S. "OKLAHOMA" IN 129 DEGREE POSITION.

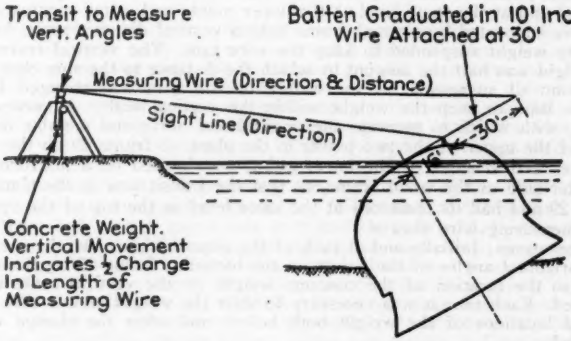


FIG. 2.—DIAGRAM OF SCHEME OF OBSERVATIONS TO DETERMINE POSITION OF TRANSVERSE SECTION OF SHIP DURING EARLY PHASES OF RIGHTING

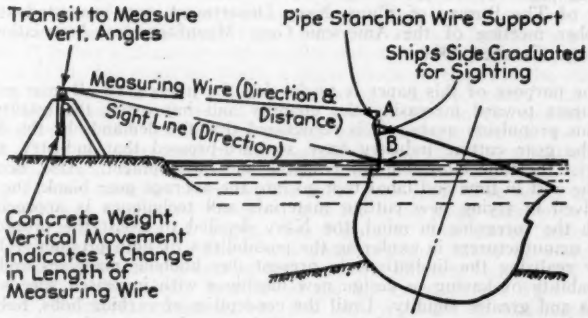


FIG. 3.— DIAGRAM OF SCHEMES OF OBSERVATIONS TO DETERMINE POSITION OF TRANSVERSE SECTION OF SHIP DURING LATER PHASES OF RIGHTING

Equipment: Two fixed points on the ship were established in the line forming the intersection of the transverse plane of frame 29 and the plane of the flat centerline keel, by the erection of a batten to give a distance of 30 feet between the two points. A distance wire (piano wire) in a plane parallel to that of frame 29 was attached to the ship three feet forward and at the same level as the upper point; and, after running over a sheave supported by a wood frame with a vertical distance scale, had a concrete weight suspended to keep the wire taut. The vertical travel of the weight was half the amount by which the distance to the ship changed. The point of suspension of the weight on the wire was changed from time to time to keep the weight within the vertical scale. A surveyor's transit, with which to measure the vertical and horizontal angular directions of the upper of the two points in the plane of frame 29 on the ship and the vertical angle of the lower point, was located on a platform on the after side of the wood frame, so that the transit was in the plane of frame 29 and had its trunnions at the same level as the top of the uppermost measuring wire sheave.

Observations: Initially and at each of the required intervals, the vertical and horizontal angles of the points on the batten at frame 29 on the ship, and also the location of the concrete weight on the vertical scale were recorded. Each time it was necessary to shift the weight on the wire, the vertical locations of the weight both before and after the change were recorded.

After approximately 17¼ months, the *Oklahoma* was righted, refloated and drydocked in what is rightly called one of the most colossal undertakings of its kind This salvage operation is regarded as one of the outstanding achievements of the Naval Engineers and is characteristic of their resourcefulness and technical skill.

CARBIDE HOBS FOR CUTTING MARINE PROPULSION GEARS.

This paper by A. J. Kroog, U.S.N.R. and R. W. Righter, Engineer, both of The Bureau of Ships, Navy Department, was presented at the October meeting of the American Gear Manufacturers Association in Chicago, October, 1944.

The purpose of this paper is to develop the interest of all gear manufacturers toward increasing the quantity and improving the quality of marine propulsion gears. It is recognized that the demands by the Navy on the gear cutting industry have so hard-pressed that industry as to restrict the time allowable for research and development. Also, because of the cost in time and labor that go into the average gear blank, the risk involved in trying new cutting materials and techniques is appreciated. With the foregoing in mind, the Navy decided to assist the propulsion gear manufacturers in exploring the possibilities of high productive hobs, fully realizing the limitations in present day hobbing machines and the probability of having to design new machines with increased speeds and feeds and greater rigidity. Until the conception of carbide hobs, hobbing procedures were one of the few metal removing operations in which production limitations remained within the cutting tool instead of the machine tool

Since Capt. E. D. Almy was known to be receptive to the idea of using hobs made of higher productive cutting materials, and since Joshua Hendy Iron Works had modern equipment, it was decided to try these new cutting tools at that plant. Many considerations went into the design of these hobs. They had to be: first, large enough to permit clamping of independent strips (cutting edges) of various cutting tool materials; second, heavy enough (backing) to support the carbide; and third,

suitable for an arbor hole of at least 2½ inches to insure maximum rigidity during the cutting action. To incorporate these features it was necessary to have manufactured a hob, as illustrated in Figure 1. Briefly, the hob was 6 inch diameter, 6 inches long, 2½ inch arbor hole with mechanically held strips to which cemented carbide cutting edges were brazed.

After examination, you gentlemen who are familiar with hobs will undoubtedly have many suggestions to offer that will improve the design of future composite hobs. Such suggestions will be appreciated. Unfortunately, no opportunity presented itself at the outset of this program for coming together with you gentlemen to discuss the initial design. Frankly, we received little or no encouragement when the idea of a carbide hob was first conceived. The information—"It has been tried before and failed"—did serve its purpose in that we gathered as much information as we could regarding the application of the other carbide hobs in order to analyze the reasons for failure and profit thereby. We in the Navy had enough experience with carbide tools to believe that such tools are capable of performing practically any metal-removing operation if intelligently applied. This does not mean that a tool necessarily should work the first time, but it does mean we feel that a properly designed tool will work if correctly applied. From our experiences with single point lathe tools, we learned the necessity for maximum rigidity and support for carbide cutting edges. From our carbide milling cutters we learned the necessity for maximum chip per tooth loads and the advantage of climb cutting. These considerations appeared to have been overlooked on earlier carbide hobs, but we feel they were the contributing factors to the success of those we used. So much for the background of the hob and its development.

Tests were conducted on a 72 inch Gould & Eberhardt hobbing machine. The maximum speed of 100 Rpm. was used in combination with .040 feed per revolution of the gear blank. The peripheral speed of the hob was approximately 150 surface feet per minute, and although this is considered on the low side for best cutting conditions with carbides, it was all that could be obtained with a 6 inch diameter hob. Climb cutting was used; i.e., feed up, rotation of hob down. Gear blank used was a C-3 pinion, approximately 21 inches in diameter with an 18⅞ inch face. See Figure 2. On the first cut at the full roughing depth, a slight knock developed in the spindle bearing after cutting about 2 inches, indicating a chipped tooth. The hob was removed and it was found that its low position on the spindle had resulted in the full load of the cutting action being taken on the lead tooth. This was corrected by moving the hob up in order to distribute this load toward the center of the hob. The hob was touched up with a diamond hone, reset, and then cut the entire gear face. The finish of the gear teeth was considered excellent, and the helix angle checked within .0001 inch in 15 inches of length. See Figure 3. The cutting action of the hob was very good. There was absolutely no chatter or vibration during any period of the cutting and the only difficulty encountered was excess heat in the spindle bearings at the top speed of 100 Rpm. This required continuous attention, but the bearings held up satisfactorily, and proved to be none the worse for the experience on later runs. The excellent cutting action is attributed to the combination of speed, feed, and climb cuttings. The chip formation was good and gave further evidence of a "clean" cutting action in that there was none of the distortion normally seen in chips that are removed by conventional hobbing.

A second hob, similar in design to that shown in Figure 1, with strips of 18-4-2 high speed steel, was run at 50 Rpm. (75 surface feet per minute, approximately) with .040 feed per revolution of the gear blank. Under climb hobbing conditions this hob performed very satisfactorily, with a clean cutting action. The surface speed of 75 feet per minute

appeared slow in comparison to the 150 feet used on the carbide hob, yet 75 feet was just about twice as fast as the speed used with regular high speed steel hobs when roughing. In order to confirm the belief that climb hobbing, regardless of the type hob used, is the most efficient manner of hobbing, where possible, this same 18-4-2 hob was used in the conventional manner in cutting a third gear at the same speed and feed (50 Rpm., .040 feed). The hob did not perform nearly as well; in fact, it dulled so rapidly that the last few inches were cut with the machine laboring noticeably.

Getting back to the carbide tipped hob; after the first run it was estimated that it would have been necessary to remove approximately .010 off the face of the teeth in order to sharpen the hob, except for the chip caused by the first setting of the hob. Figure 4 is an enlargement of the carbide cutting edges before use, and Figure 5 shows their condition after cutting a C-3 pinion.. In order to remove this entire chip before a re-run, 1/16 inch was ground from the face of the teeth This thinned the carbide insert down to 5/32 inch, which is entirely too thin for recommended practice. The face of the teeth was carefully finished and the feather edge that developed during grinding was removed. A very fine diamond hone (at least 220 grit) must be used for this operation and extreme care is necessary in order to remove the feather edge without actually dulling the tool. The hob was then used to cut another C-3 pinion and performed equally as well as the first run. In fact, the carbide itself showed no signs of chipping as had occurred in the first run.

It is planned to modify a 72 inch Gould & Eberhardt machine in order to get the increased speed and rigidity necessary to determine the productive possibilities of composite hobs with many of the hobbing machines now available. These modifications will result in:

(a) Spindle speeds up to 194 Rpm.
(b) A small fly wheel on the overhanging end of the arbor.
(c) Automatic force feed oiling system.
(d) An upper tie bracket steady rest.

As soon as these features have been added and tested, information will be made available as to the feasibility of modifying other machines. Further plans call for the manufacture of finishing hobs and additional strips for both the finishing and roughing hobs as follows:

(a) R.H. (Finishing) Kennametal grade K-4-H.
(b) L.H. (Finishing) Carboloy grade 78.
(c) R.H. (Finishing) Vascoloy-Ramet grade E.
(d) L.H. (Finishing) High Speed Steel (18-4-1) deep freeze treatment.
(e) R.H. (Finishing) High Speed Steel (18-4-2) deep freeze treatment.
(f) R.H. (Roughing) Vascoloy-Ramet grade Tantung G.
(g) L.H. (Roughing) Haynes Stellite grade 98-M-2.
(h) R.H. (Roughing) High Speed Steel (18-4-1) deep freeze treatment.
(i) L.H. (Roughing) High Speed Steel (18-4-2) deep freeze treatment.

The following indicates the approximate conditions under which it is planned to run the hobs.

	Speed		
Roughing	*Rpm.*	*Peripheral (Ft. per min.)*	*Feed Per Rev.*
High Speed Steel (18-4-1) R.H...	50	75 (approx.)	.040
High Speed Steel (18-4-2) L.H...	50	75 "	.040
Tantung G.R.H.	80	120 "	.060
Stellite (98-M-2) L.H.....	80	120 "	.060
Finishing			
Kennametal K-4-H R.H.....	180	270 (approx.)	.090
Carboloy 78 L.H.....	180	270 "	.090
Vascoloy-Ramet E R.H.....	180	270 "	.090

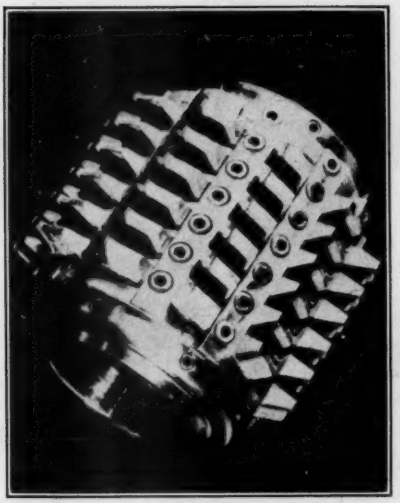


FIGURE 1.

Carbide Hob. Cemented Carbide Tipped Kennametal K4H, Approximately 6 Inch Diameter, 11 Gash, .6283 C.P., 5 N.D.P., 2 Degree 6 Foot Ang.,—R.H. Straight Gash, 14½ Degree Nor. P.A. .4314 D&F. Sin., Rough, Body 1040 H.R.S., 48-52 Rockwell "C", Strips with Kennametal Cutting Edges Held in Place on Hob Body by Tapered Wedges and Set Screw.

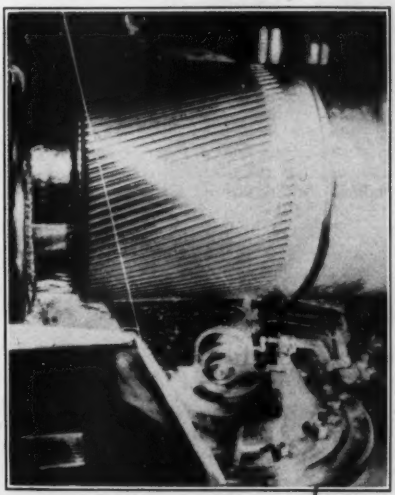


FIGURE 2.

Carbide Hob—Climb Hobbing. C-3 Pinion Approximately 21 Inch Diameter with 18⅞ Inch Face Width.

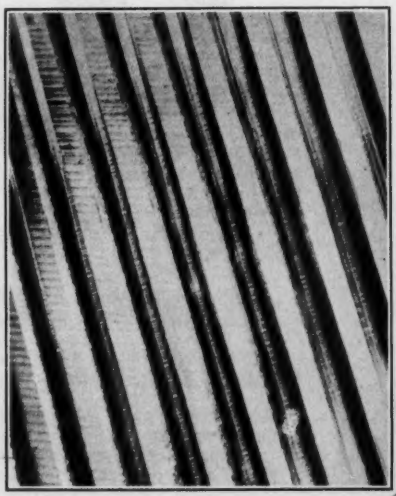


FIGURE 3.

Gear Tooth Finish on C-3 Pinion as Cut by Carbide Hob. Note That No Burr was Left Due to the "Clean" Cutting Action.

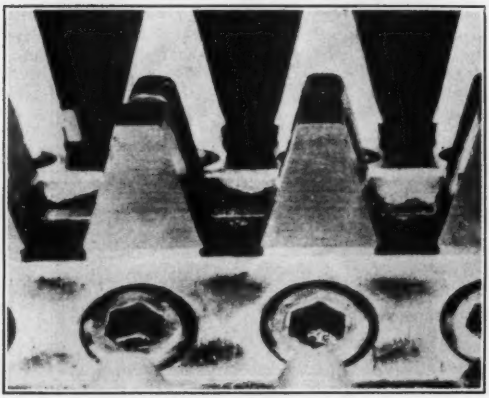


FIGURE 4.
Carbide Inserts (Cutting Edges) Before Use.

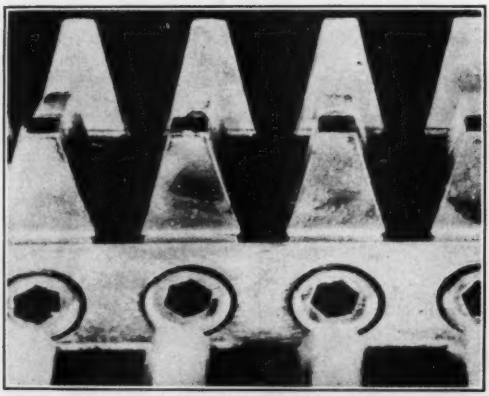


FIGURE 5.
Carbide Inserts (Cutting Edges) After Cutting a C-3 Pinion.

Tantung and Stellite are cast alloy cutting materials having high red hardness, and are good roughing tools. It will be noted that they fall within the ranges of speed and feed available on present G. & E. 72 inch hobbers; also, it will be noted that the speeds selected for the carbide finishing hobs are based on the proposed modifications to increase the spindle speed to 194 Rpm.

In addition to the above, consideration is being given to the possibilities of having made a new 96 inch dual head gear hobbing machine. In fact, preliminary drawings and specifications have been submitted to the Bureau of Ships. Although it is not possible to give full details at this time, it can be said that this new machine will be much heavier and sturdier than similar machines now in use. Also, that it will be designed entirely for use with carbide hobs. It is hoped that carbide hobs and new hobbing machines will make it possible to cut gears of a higher tensile strength and hardness than has been heretofore possible. You gentlemen can appreciate what that will mean, in that such gears will be capable of transmitting more power per inch of gear width and will undoubtedly have much longer life. Under good operating conditions for carbide hobs it is believed that much greater tool life can be expected. In fact, it is perfectly possible that several gears can be finished with one sharpening of the hob. This, of course, can only be proved by tool-life test.

The entire project will be carried to the point where definite data can be tabulated as to just what production can be expected from available equipment. Also, it is hoped to determine production possibilities under more or less ideal conditions using carbide hobs in combination with a new design of hobbing machine.

ELECTRICAL MACHINERY FOR USE WITH SHIPS' AUXILIARIES.

This paper, read by R. S. Blackledge, was published in the transactions of The Institute of Marine Engineers, December, 1944.

Introduction.

The subject of electrical machinery now embraces so much ground that any single paper must contain a definition of its scope.

The present contribution deals with dynamical, thermal, overload, commutation and noise characteristics, with insulation, with cooling by forced convection, and contains general notes on application of the types of rotating electrical machinery which are being, or are likely in the near future to be used for the motoring of ships' auxiliary machinery. Because of space limitations these subjects here are discussed more from the point of view of the general engineer than of the designer; where necessary, design topics are introduced because it is not possible to divorce the subjects of satisfactory performance and successful design.

Dynamical Characteristics.

The dynamical characteristics of an electric motor may be defined as a statement expressing the relation between speed and torque. There are two general types known respectively as the "shunt" or "constant speed", and "series" or "inverse" characteristic. These expressions clearly are qualitative only, and frequently they are not adequate to define a particular duty.

The shunt or constant speed characteristic dates from experience with the non-interpole casually ventilated shunt wound motor, which had a torque-speed curve with little variation, as is shown in Figure 1. In general, on modern interpolar machines with their increased electric

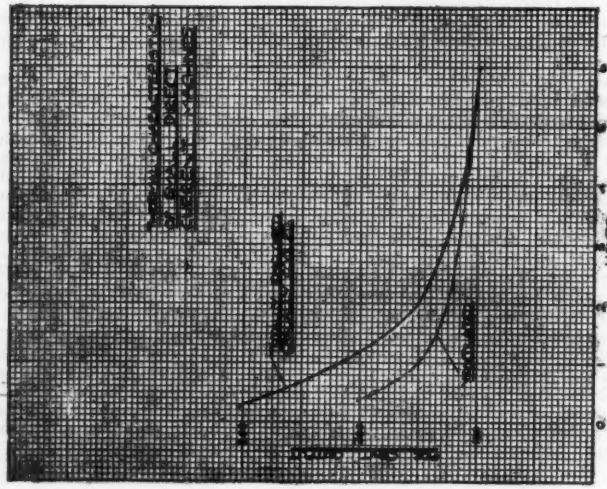


FIG 2

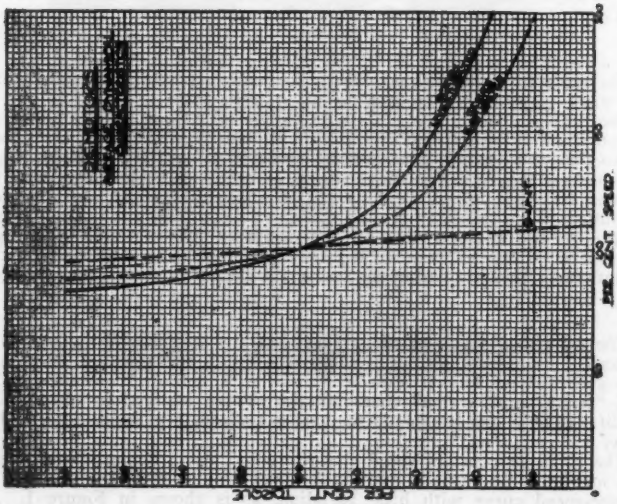


FIG. 1.

loadings, the attainment of such a relation would necessitate a cumulative series field winding, the machine then being described as "compound wound with shunt characteristic" or "shunt wound with series stabilizing turns".

An analysis of the causes which contribute to the speed regulation with load has been given by the author on a previous occasion[1] and it would appear that some of the engineers who consider it necessary to specify the amount of speed variation with load have not on all occasions given the matter the consideration which it deserves. It is indeed seldom that the speed regulation with load of a constant speed shunt characteristic motor need be specified; again, in connection with compound wound shunt characteristic machines, specifications have been known to lay down the maximum series field magnetomotive force, a quantity that is quite meaningless except to the designer of the machine. The causes of this non-linearity between torque and speed on modern machines are three. In the first place, there is the reduction in working flux with increased armature current resulting from cross-magnetization of the main magnetic circuit by the armature magnetomotive force; secondly, there is the direct axis action of the parasitic currents circulating in the coils being commutated; and thirdly, lack of correct adjustment of the interpole strength, whilst not giving rise to prohibitive sparking, might be sufficient to increase the second effect of direct axis magnetization. It has been assumed that the brushes are set in the neutral plane, and if this is not so there would be boosting or bucking of the second effect.

The normal induction motor operating with short circuited rotor has the shunt characteristic within a zone extending from zero slip to approximately ninety per cent of the slip corresponding to maximum torque; the physcial meaning of the shapes of the working ranges of torque-speed curves of the direct current shunt machine and the induction motor, have a general identity except that the direct current case has more important secondary factors. The first order trend is due to the interdependence, with constant flux, of torque and working current; that is, the shunt characteristic direct current motor slows down with increased torque demand so that the reduced induced Emf. will allow the impressed voltage to propel the increased armature current necessary to give the larger torque. The induction motor slows down with increased torque demand so as to allow an increased rate of flux cutting between rotating magnetic field and the winding carrying the working current. This greater rate of flux cutting results in an Emf. which within the range of stability has a rate of increase greater than the impedance of the winding, which results, assuming constant flux, in increased torque. Both types of machine have secondary effects brought into play by what may be described as the primary changes, but as has been stated above it is alone in the direct current machine that the secondary effects are able to bring about a relevant change in the shape of the machine characteristic.

The series characteristic is governed primarily by the amount of magnetic saturation. Let there be considered first a machine without losses and saturation and with zero incremental excitation; the torque, being proportional to the product of flux and armature current will vary as the square of the current, and the flux, to which the speed is inversely proportional for a given voltage, will vary as the current. It will be seen that the product of the speed and the square root of the torque will be constant.

In the series motor, with appreciable saturation and taking account of the losses, it will be found that within the working range approximately the torque is proportional to the current and the relation between speed and current is given by a first quadrant rectangular hyperbola. The torque-speed function, therefore, has the same shape as the current-speed. It is in practice convenient to think of two series characteristics known respectively as the "saturated series" and "unsaturated series"; they are shown

in Figure 1. The extra saturation is generally introduced in the armature teeth, and, depending upon the frequency of the machine, it might not be possible thus to design in any particular case because of the resulting iron loss not being allowable for the temperature rise that is permitted.

The wound rotor induction motor operating with external resistance in the rotor circuit has a speed-load characteristic which approximates the series but there is not, as there is in the shunt characteristic case, a similarity in the dominant cause; in the series machine it is a current-flux mechanism.

Again, it is possible to design the rotor of an intermittently rated squirrel cage induction motor so that the torque-speed curve has most of the features of the series characteristic—although it must, as indeed is the case of the wound rotor motor with external resistance, be convex instead of concave towards the origin—by arranging for a large rotor copper loss, larger, unfortunately, than we can arrange to cool continuously.

The series wound machine sometimes is fitted with a shunt field in order to reduce the increase in speed with decrease in load and by suitable adjustment of series and shunt magnetomotive forces it is possible to give a wide range of speed-torque characteristics It is convenient to refer to the restrained speed increase machine as being "Series wound with limiting shunt".

In the same way a shunt wound machine may be fitted with a cumulative series field heavier than that necessary merely to stabilize it, in order to increase the rate of increase of torque with armature current.

For special duties it might be desirable to differentially compound a motor but it is necessary in doing so to take special care that the machine does not run away with increased load.

Some auxiliary drives, notably ventilating fans, permit the super-intending engineer a choice of the use of either shunt or series motors, and the question has been asked what factors, other things being equal, should determine the type to be used. The series motor has a better transient performance than the shunt because the additional inductance of the field circuit is then in the armature circuit; not only this, the series field helps to kill a current surge by building up the machine voltage. There are cases, for example, in which it is desired to have smooth control of the volume of air over a range of speed, in which it is probably the better practice to use shunt characteristic motors; this is a matter upon which generalization cannot be attempted and it is necessary to examine each scheme on its merits. Two statements in favor of the series motor may, however, be made. The shape of the torque-speed curve of the fan is very nearly quadratic for constant orifice, or at the worst a series of approximate quadratics, so that the shape of the series characteristic makes the combination self protecting in the matter of combined dynamical characteristic—a very desirable feature. In the second place, the series wound motor is always a more robust machine electrically than is the shunt—this is by virtue of the inductive and excitation building properties mentioned above.

Thermal Characteristics.

The thermal characteristic, unlike the dynamical relation, is not capable of full representation in the single plane. In the past it consisted of a horsepower or current/time function used chiefly in connection with electric traction problems. The variables involved are as follows:

(*a*) The type of enclosure.
(*b*) The method of ventilation or cooling.
(*c*) The period of duty.
(*d*) The periodicity in recurrent cases.
(*e*) The distribution of the losses.

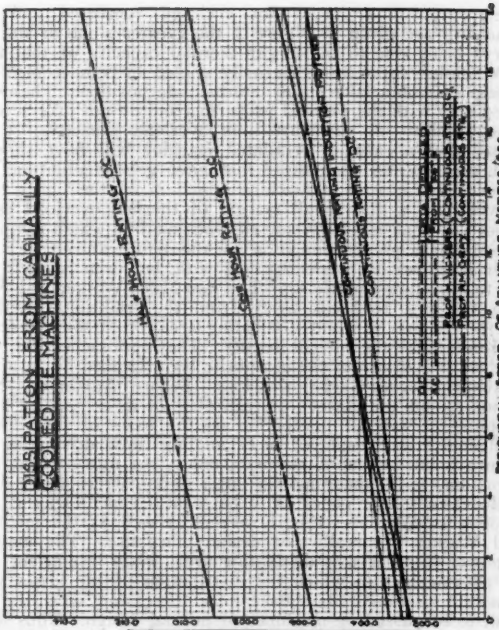

DISSIPATION FROM CASUALLY COOLED TE MACHINES
Watts Per Square Inch Per "F Rise
Peripheral Speed of Armature Metres/Sec

Fig. 4.

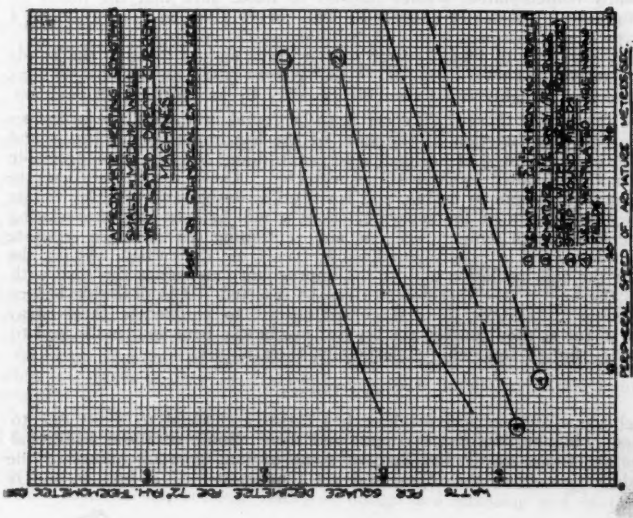

Watts per square inch per "F rise
Peripheral Speed of Armature Metres/Sec

Fig. 3.

Generalized output-time curves for enclosed ventilated and totally enclosed machines are given in Figure 2, the greater slope of the totally enclosed curve being due to the larger thermal capacity of that type of machine. A similar curve for externally cooled or wind-cooled totally enclosed machines would take up an intermediate position. These curves are concerned only with the thermal properties and do not take account of commutation, stability, or of short time overload capacity. It is not difficult to see that a casually ventilated machine will have short time thermal capacities greater than those that have good ventilation, and at the distant end of the scale a machine which is on the limits of over ventilation will have a very small margin of thermal overload capacity.

There is not for small machines any rigorous method which has pretence to even approximate predetermination of the temperature rise; on the whole, larger machines are easier to deal with, but even in their case it is necessary to introduce empiricism. The late Miles Walker and Symons[3] were among the first to break away from the traditional method of utilizing the power loss per unit dissipating area, or in some cases—still, in general, more crude—the current density. They approached the problem as one of heat flow. Consider the composite body formed by an armature or stator having a segregrated power loss. Before Walker and Symons it was common to sum the power loss regardless of its component amounts and to compute the rate of dissipation on the basis of the total area. And what ingenuity was displayed in calculating those dissipating areas! This procedure is unreasonable, however, unless the rate of heat generation is proportional to the mass and the latter to its corresponding dissipating area. Hoseason's later paper[2] is to be regarded in its way as a landmark in cooling calculations; this, however, as well as the methods of Symons and Walker are really for design office use. The method of taking the power loss per unit dissipating area, while insufficient for the comparison of machines in which the distribution of the losses vary is, when used with discretion, quite sufficient for forecasting when the danger limit is about to be passed on machines of normal design. Thus it might be that the purchaser, having modified the duty or operating conditions originally contemplated, wishes himself to make sure that the limits of heating safety will not be exceeded. The curves given in Figures 3 and 4 are typical of those which should be used for that purpose.

Many such curves from several sources have passed through the hands of the author and there is no doubt that curves based on the observations of testers of roughly equal competence, vary by as much as 30 per cent.

The reason for these differences is to be found in making the ordinates of the curves a function of the sum, of the legitimate copper losses and an iron loss measured at no-load, whereas in doing so quite an appreciable term in the so-called "stray-loss" is neglected. These stray losses vary in amount from design to design, and for a given design and total legitimate loss with the ratio of the separate losses, it will be seen that the relating of the losses with temperature rise and ventilating conditions in separate tests is not, even in experimental work, free from difficulties. Again, the type of the coil insulation and of the impregnant determines the ease with which the bulb of the thermometer can be inserted. It is desirable before proceeding to further thermal considerations to enumerate these stray losses so far as they concern the type of machinery here dealt with, and to examine, though somewhat superficially, their nature.

Stray Losses.

Each class of electrical machine has losses additional to those due to friction, windage, legitimate copper and iron. Some of these additional losses are functions of flux density, some of load current, others of the one dependent upon the other, and yet the amount of a further one is

almost accidental in nature for it is dependent upon the events of commutation.

The direct current machine has the following sources of stray load loss:

(*a*) The additional armature copper loss due to current displacement. Assuming linear commutation, the wave shape of the armature current may be taken as trapezoidal; the width of the commutating zone determines the major harmonics in terms of the fundamental. As the current wave shape is expressible readily in a Fourier Series, practical harmonic analysis does not enter and computation may be carried out straight away for the separate harmonics on the lines set out in the now classical papers of the brothers A. B.[4] and the late M. B. Field[5]. Dr. A. E. Clayton of the University of Manchester has taken an interest in the subject and Dr. Hanney when he too was there published a valuable paper[6] containing curves from which the loss may be quickly estimated.

(*b*) The armature copper loss due to the transverse slot flux resulting from highly saturated armature teeth is primarily a function of flux density, but since on load the flux density under one of the pole horns is increased by cross-magnetization, it is a function also of the load current. This loss can be measured with reasonable accuracy by observing the light load loss against flux for the relevant frequencies. The method of separation is shown in Figure 5. It is probable that Ottenstein[7] was the first to attack this problem quantitatively, and a modification of a formula given later by Lamme[8] (late Chief Engineer of the American Westinghouse Electric and Manufacturing Co.) has shown good agreement with test. A more complete method has been given by Miles Walker[9]. At high flux densities this loss may increase faster than the fourth power of the induction.

(*c*) The losses caused by currents circulating in the coils undergoing commutation, due to unbalanced voltages at the brush. In most cases, although the commutation visibly is perfect, there exists a gradient in brush voltage which propels the parasitic current giving rise to this loss. With the brushes set in the neutral, as has been stated already, the resulting magnetomotive force acts along the direct axis. An experimental determination of this loss has been made but the subject is too lengthy to be pursued here.

(*d*) Pole face losses. The magnetic pulsations set up by the armature teeth penetrate radially beyond the pole face for small depths which vary with many factors, the resulting eddy currents giving rise to the pole face losses. In general, for machines of the size considered in this paper, factors which would give rise to appreciable pole face loss would lead to a design inadmissible from other points of view. A recent paper by Aston and Rao[10] gives valuable information on the subject as well as a good list of references.

(*e*) Incremental legitimate iron loss due to cross magnetization. The increase in flux density under the horn of the main pole which is cumulatively magnetized by the armature magnetomotive force gives rise to increased eddy current and hysteresis losses in the armature teeth, and also increases the pole face loss. Unless the resulting flux density is very high—in which case the loss under discussion cannot with certainty be separated from that described under (*b*)—this incremental loss due to cross magnetization may be obtained by observing the iron loss at no-load at a flux corresponding to that under the strengthened horn. The method of obtaining such a flux is described (amongst numerous places) in reference[3].

(*f*) Iron losses in the teeth under the commutating poles. It is seldom that this is of moment and its small amount may well be allowed for in the total—bearing in mind the necessarily approximate nature of the whole subject—by a small increase in one of the empirical coefficients. This statement assumes conventional interpole design and stressing and so far

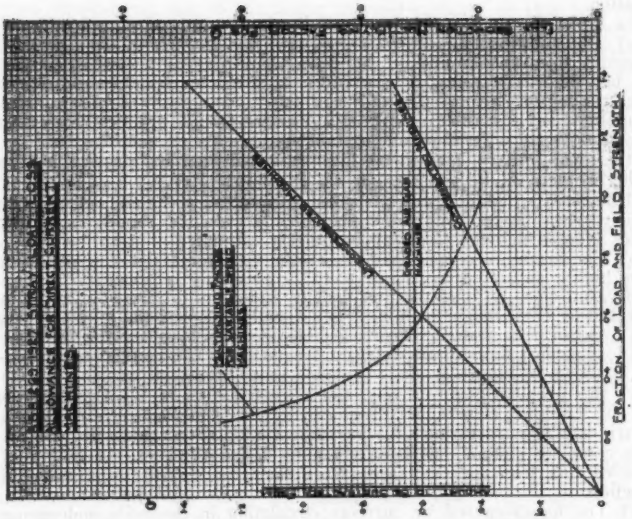


FIG. 6.

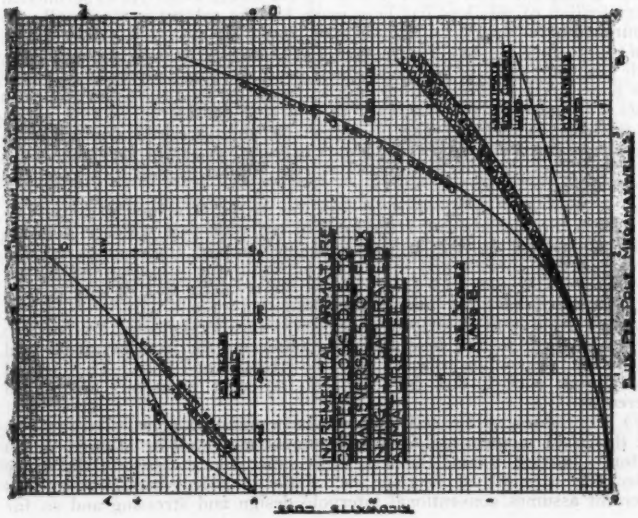


FIG. 5.

as can be envisaged it is justifiable to think of it as likely to hold good; it is, however, possible that higher flux densities might be utilized in particular classes of machinery in this part of the circuit, in which case methods already known could be applied in the computation of the losses in the interpole teeth.

(*g*) Eddy current losses in solid masses, e.g., coil supports, end plates, etc., which are linked with useful or stray fields. There are cases in which this component is by no means negligible but unless there is evidence of local heating it is not difficult to deduce that the loss must be less than a calculable amount and a further adjustment to one of the empirical constants would take care of the allowance. The manner in which the loss varies with the size and disposition of the solid masses has not been investigated in a scientific way except for large machines of the synchronous type.

Induction and synchronous machines, polyphase and single phase commutator motors, synchronous and cascade convertors, and static transformers all have their quota and types of stray load losses, and although each has losses which may be said to be physically members of the same family, each also has types of loss peculiar to itself, sometimes by virtue of its accepted method of construction.

The purchasing and operating engineer will generally be interested, it is thought, not so much in the accurate analysis—observational or theoretical —of these stray losses, as in their approximate total amount.

In British practice (B.S.S. 269/1927) allowance for stray load losses is made by reducing the efficiency calculated on the basis of the no-load core, friction, windage, and the so-called direct load loss, which in effect is the total copper loss calculated on the basis of direct current measurement of the resistance, except in the case of synchronous machines where the eddy current loss in the stator winding is measured in a short circuit loss test.

In the case of direct current machines in which the speed is varied by field reduction, the factor that is subtracted from what we might term the conventional efficiency is increased by multiplying by a tabulated function of the amount of flux reduction. Machines having graded air-gaps—that is, in which the gap at the horn cumulatively magnetized, is increased, and at the other end decreased so as to equalize the air-gap flux density at full load, but incidentally to make it asymmetrical at reduced loads—have their conventional efficiency reduced by a constant amount for constant speed, but with flux reduction the amount is increased as for the symmetrical gap machine. The above facts are shown graphically in Figure 6.

The proposed Test Code for Direct Current Machines of the American Institute of Electrical Engineers does not take account of stray losses on machines having outputs less than 200 horsepower at 575 Rpm., and on the larger sizes they are taken as one per cent of the output.

In the experience of the author the methods set out in B.S.S. 269 and the proposed D.C. Test Code of the American Institute of Electrical Engineers are open to criticism. It is in the nature of the problem that at the best such allowances cannot under all circumstances be exact, but at least there should be resemblance between the formula of correction and the law of variation of the factors involved.

The polyphase induction machine has stray load losses due largely to increased losses in the iron and rotor copper occasioned by flux wave shape changes with load. There are, too, eddy current losses in the stator conductors and any solid clamps. Koch was one of the pioneers in the experimental elucidation of this subject and many of the ideas contained in his 1932 paper[11] are incorporated in the American Institute of Electrical Engineers' Test Code for Polyphase Induction Machines (1937). By that code the determination of the stray load losses of a squirrel cage motor is made by exciting the stator with direct current and driving the rotor at synchronous speed. The net driving power is reduced by the amount

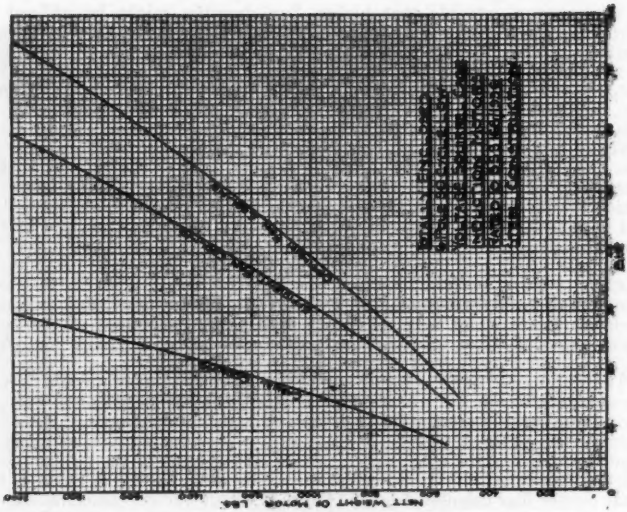


FIG. 8.

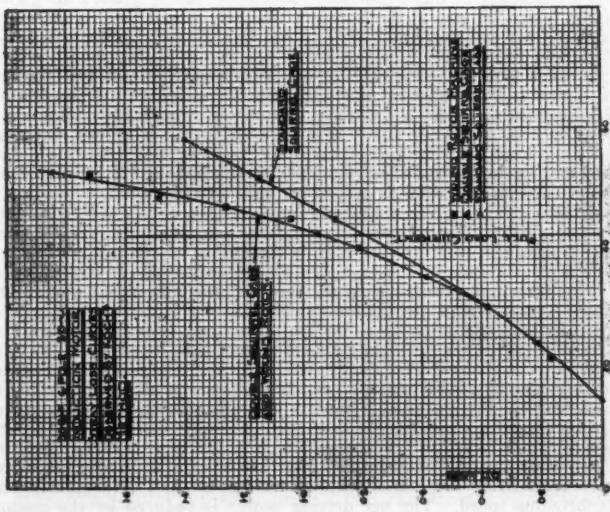


FIG. 7

of the rotor copper loss corresponding to the chosen equivalent stator current, and the residue is the stray load loss as a function of the stator current. Under these circumstances the stray load loss curve will intersect the abscissæ axis at the magnetizing current equivalent.

This test procedure is not absolutely correct from a theoretical standpoint but based upon two independent methods of deduction it would appear to give the correct order of the loss. The curves given in Figure 7 were taken some time ago, before experimental work had shown the lines along which reduction of stray losses should proceed, nevertheless the shape of them is representative.

With increased slips the stray loss as measured above decreases, approximately as the square of the speed, but the loss due to displacement, currents in the rotor bars increases; in rotors of the "deep bar" type this increase is appreciable.

Koch gave the order of the true stray load loss in induction motors as from 2 to 5 per cent of the output for machines of from 1 to 5 Bhp., decreasing gradually with output to less than 1 per cent in motors of several hundred horsepower. It is probable that in the average these amounts are of the correct order, but the actual figure depends upon the finer points of the design. B.S.S. 269-1927 allows for this by subtracting from the conventional efficiency the amounts given in Table I.

TABLE I.

Load on basis of load with overload rating.	Deduction form efficiency.
1¼	0.625
full	0.5
¾	0.375
½	0.25

The determination of the stray load loss in synchronous machinery is made under short circuit conditions; generally with large sets there are facilities for loading to rated K.V.A. at zero power factor. There is frequently a large difference between the stray load losses measured by the two methods, considerably larger in fact than can be accounted for merely by the changed saturation in the circuits of the stray flux. For example a test is recalled in which the stray load loss measured on Zero Power Factor was 138 Kw. whilst that measured on short circuit was 181 Kw., but the percentage deviation of the true stray load loss is much greater than would be gathered from those figures because each contains an invariable and calculable eddy current loss in the slot portion of the conductors. In saying that this portion is invariable it must be realized that in fact the greater flux of the load test does slightly alter the slot portion eddy loss but it is not within the competence of present methods of calculation or experimental technique to measure the variation. The whole subject of stray load losses requires further research.

COOLING BY FORCED CONVECTION.

The totally enclosed machine must be large in terms of its output because it dissipates its losses from the carcase surface; it is, in fact, uneconomical to construct for outputs greater than some 25 Bhp. at 1,000 Rpm., and unreasonable to build for 50 Bhp. The reason for this limitation in output, though not its magnitude, is not difficult to follow if the machine is thought of as having a boundary that is easily expressed symbolically. Assume for example that it is a sphere. For the same percentage of homogeneity the watts to be dissipated would vary approximately as the volume, that is as the cube of the radius, whereas the ability to dissipate varies as the surface, or the square of the radius. The temperature rise for equal stress intensities therefore varies as the radius. Conversely, a limit is fixed, say 50 Bhp., beyond which it is not reasonable

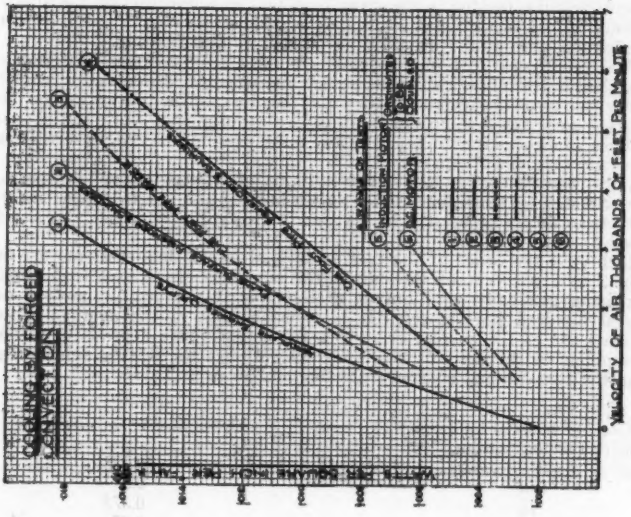

COOLING BY FORCED CONVECTION
VELOCITY OF AIR THOUSANDS OF FEET PER MINUTE

FIG. 10.

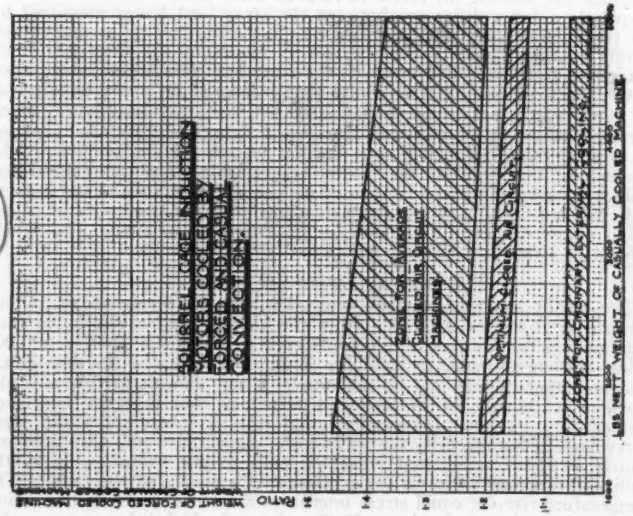

SQUIRREL CAGE INDUCTION MOTORS COOLED BY FORCED ANDNATURAL CONVECTION
LBS. NETT WEIGHT OF CASUALTY COOLED MACHINE

FIG. 9.

to increase the size of the machine, and, working downwards to the smaller machines the stress intensities may be increased for the same percentage homogeneity and temperature rise.

The induction and direct current machines have an important distinction in this matter of heat dissipation. In the former some 70 to 80 per cent of the total losses are in metallic conduction contact with the dissipating surface, the remainder—the rotor loss—having to traverse uncertain and often almost circumstantial air paths. In the direct current totally enclosed machine, on the other hand, some 50 to 70 per cent of the losses contributing to the heating must find their way to the exterior dissipating surface via those uncertain paths. Thus it is that the induction machine has a factor of loss dissipation (watts loss/temperature rise $\times$ dissipating area) superior to that of the direct current machine.

External—or as some term it, wind—cooling, in which an external fan drives cool air over the carcase, is the natural method of attacking the disadvantages of the casually cooled totally enclosed machine. During the past two decades many ingenious ideas have been introduced, but the employment of comparatively crude schemes gives at once a large increase in output over that obtained with casual cooling.

Figure 8 shows the improvement which is realized as the divergence of the curves increases with the speed. For larger sizes intimate air mixing is beneficial; here a designed internal circuit is brought into intimate contact for part of its path with blown cool air. In general this scheme adds considerably to the weight of the machine (Figure 9) but the additional weight is more than compensated for by the gain in output.

The air stream mounted machine would appear to have a future for ventilating work because of the high efficiency of the axial flow fan when compared with the cased centrifugal fan. The conditions for cooling the motor are much the same as in the externally cooled type of motor. Much data on the forced convection cooling of single cylinders and planes has been published under the subject of heat transfer, and again useful matter has been given in connection with the cooling of aero-engines; some of this information is given in Figure 10. It is necessary to modify the function of these expressions because in the electric motor the temperature rise of the carcase must necessarily be less than that of the internal parts. The ratio of the temperature rise of the hottest internal part to that of the external surface varies between 1.3 and 2.7 for externally cooled machines. A figure of 1.5 was taken in modifying the curves of Figure 10.

In a comparison of the cooling by this method of different classes of machines, it is necessary to take account, as was implied above, of the distribution of the losses as well as of the amount.

Commutation.

The introduction of interpoles into standard lines of machines dates back to about 1906, but accurate interpole design did not come into being for quite a time after that. The late Miles Walker's "Specification and Design of Dynamo-electric Machinery", now almost 30 years old, could not be regarded as wholly satisfactory in its treatment of the subject, but it is probably indicative of the state of the art at the time of its publication; indeed to the best of the knowledge of the author, the finer points have yet to be published

Prior to the introduction of interpoles, commutation was frequently the feature that limited the output of a machine, and commutation criteria of variable speed ratings which to-day are commonplace would not then have been possible.

A list of troubles which commonly are ascribed to commutation would amount almost to a catalogue, but the larger part of them would be due to faulty collection, not to commutation as such. In recent years there

has been much study of the effect of inertia and frictional forces of the brush itself, the inertia of the resolved components of the brush holder mechanism which react against a radial movement of the brush, and of the effects of resilience. There are, too, chemical aspects of the problem.

The problem of collection may be said in general to increase in difficulty with speed and because of this the theoretical formula for reactance, involving as it does the first power of the speed is not a unique guide to the obtaining of a machine with sparkless characteristics.

Commutation, or collection, is not necessarily faulty if it is not absolutely black. The British, U.S., and V.D.E. Specifications are a little vague on this matter; the former makes tacit avoidance of the real problem, whilst the latter two, in effect, make use of the expression "that there shall not be unreasonable wear", a statement that in some circumstances might be difficult to define. In this, as in numerous details, the specifications are to be regarded as frameworks of guidance, and it is for the manufacturer to set and maintain the standard which good engineering dictates.

The skewing of the slots of a direct current machine is resorted to frequently with the purpose of smoothing out slot ripple in the flux wave shape. This is an aid to commutation if the design of the whole magnetic circuit is made to correspond. Cases have been met, however, in which this has not been done, and then slot skewing impairs successful commutation. It is quite possible that when precautions are not taken, the interpole magnetomotive force which supplies the flux for the commutating Emf. might have to be increased by as much as 100 per cent, which means an increase of some 20 to 40 per cent in the interpole excitation. The leakage flux at the root of the interpole of a modern machine varies from 1.5 to 2.5 times the useful commutating flux (direct current machines alone are being discussed) whilst the leakage flux at the root of the main pole varies from 12 to 20 per cent of the useful main flux, a ratio of some 12 to 1. Therefore, the interpole leakage flux in effect decides the saturation of that circuit, and hence in turn the correspondence between demand and supply of correcting Emf. Since the leakage flux is proportional to the magnetomotive force if the coils are similarly disposed, an attempt to compensate for an incorrect magnetic circuit used in conjunction with skewed slots after the machine is constructed might bring a deal of trouble.

A machine having saturated interpoles which are adjusted to withstand overloads will have overcommutation at lighter loads, and unless it has an appreciable cumulative series field there will be instability on reduced loads.

The stator fed and rotor fed types of polyphase shunt characteristic commutator motor formerly had, even with the most careful and skilled design, serious commutation limitations; so much so that it was a rare experience to meet one that had an appreciable temperature rise at full load and normal speed. The output in horsepower per pole was limited to about 15. The major trouble here is the cutting of the coils being commutated by the main flux wave, there are also important secondary effects which, however, cannot be discussed in a general paper.

During recent years two most admirable developments have been made, one by Schwarz[15] in connection with the stator fed machine, the other by Robinson[16] of Schenectady for rotor fed motors, or as they are generally described "Schrage" motors.

These inventions consist of the application of suitably pitched and thrown windings housed beneath the commutator winding, magnetically shunted therefrom but inductively coupled, and connected to the commutator. The auxiliary winding absorbs by conduction most of the energy that formerly was dissipated in sparking at the brushes, and transfers it by transformer action and conduction in turn over as much of the

main and commutating windings as may be necessary to discharge it. Machines incorporating these auxiliary windings can be built for much larger outputs and have very good commutation even at high speeds.

It is not impossible, in the event of the alternating current motoring of auxiliaries becoming accepted practice, that consideration will have to be made of the single phase neutralized series motor for certain duties, and for more than 30 years engineers have persevered to bring the motor to its present desirable form. This type of machine has a dynamical characteristic similar to that of the series motor, and it may be said that the whole of the troubles connected with its development have resulted from commutation difficulties. Lamme and his collaborators at the American Westinghouse Electric and Manufacturing Co. and the Oerlikon and Siemens Schuckert firms have done much towards making this type of motor satisfactory in the hard field of electric railway work.

Noise Characteristics.

Electrical machinery operating near, or connected by trunking, piping or the like to passenger accommodation, must be as silent as possible, and during the past 15 or 20 years much valuable work has been carried out, chiefly on reduction of magnetic noises. Many years—40 or more—ago suggestions were made for particular relations between pole arch and tooth pitch, but as Hawkins said in Volume 1 of his book "The Dynamo", they have not proved their usefulness. A direct current machine of the sizes we have in mind can be made silent if cost and size are of no importance, but there must always be competition, and research has been towards the design of a silent machine with the maximum electric and magnetic loadings. Vibration of the yoke, or shell, and frame plays an important part even in relatively small machines, and within the experience of the author a machine which was quite silent when fitted with a yoke of cast iron became noisy when a cast steel yoke of reduced section (the reduction in section was possible because of the better permeability of the steel) was substituted.

Radial vibrations of a long cylinder are treated in A. E. H. Love's classical work[14], and Den Hartog[15], Stephen Timoshenko[16], and F. W. Carter[17] have discussed the practical problem.

Noise may be classified under separate headings according as it is due to:—

(*a*) Magnetic fields.
(*b*) Windage.
(*c*) Bearings.
(*d*) Other mechanical causes.

Assuming normal operating speeds, windage, bearing, and other mechanical noises do not present serious trouble, although if really silent running is required sleeve bearings are necessary . Careful design of the cooling fan and of the internal air circuits will reduce the windage noise to an amount that is permissible, and in any case this component may be made as small as necessary by slightly derating and passing less cooling air.

Sometimes brush noise is appreciable and it might be that the quality of brush which would be chosen to avoid noise is not that which commutation dictates. Brush noise is not readily transmitted as its energy is small, and if the machine is enclosed the problem ceases to be a serious one at normal speeds.

In dealing with the question of magnetic noises it is necessary to take the different types of machines separately. In the direct current version most of the trouble arises as the armature teeth leave the pole. There are powerful forces acting between the pole horn and the teeth, and they undergo a cyclic change during the passage from one main pole center to the next. In multipolar machines in which the horn considered as a

cantilever necessarily must be quite rigid if it is to pass its share of flux through the bridges, it is unusual for vibration of the horn to take place, but this is not always true in two-pole machines in which the cantilever properties of the horn are much weakened. Then there is the vibration of the armature tooth as a cantilever under the action of the tangential component of the tractive force. The yoke or shell itself might be set into pulsation and when it is considered that generally the yoke is fitted at either end with brackets having machined shoulders making a light driving fit into its own spigots, it will be seen that the composite problem is very involved. Flexure of the end shields has indeed been known to take place.

While the ability to predetermine the vibrational properties of the yoke and end shields is very desirable, the cure lies primarily in the elimination or reduction to suitable values of the flux variations, and although this involves time phenomena the flux space wave shape has a most important bearing on the time rate of change.

Ranges of standard machines are built up in steps of diameters, there being two or three core lengths to each diameter. The shaft diameter is computed on the basis of a permissible inter-bearing deflection on the longest core length, but a shaft calculated alone on this will not be stiff enough for a super-silent machine unless the flux density is reduced.

In direct current machines the configuration of the pole face and the number of slots as well as the rigidity of yoke, end shields and shaft have an important bearing on noise, and it is probable that in the years immediately post-war considerable reduction will be effected in the amount of noise emitted by ordinary commercial motors.

The subject of magnetic noises in induction motors is a very wide one. It can conveniently be divided into two broad kinds, viz., (*a*) noises which occur during acceleration, and (*b*) those which occur during running. The running noises also are broadly divisible into two kinds, viz., (1) those which occur on no-load, and (2) those which come into being with the load.

The noises which occur during acceleration result from a particular case of some of the phenomena which come into play in connection with the on-load running noises.

The no-load magnetic noise of an induction motor having normal saturation is almost entirely "transformer" noise, that is the noise spectrum consists of a fundamental of frequency equal to twice the exciting frequency, together with a string of harmonics, and the total can be reduced sufficiently for most purposes. The attainment of real silence with present dynamo steels, however, means derating. It is probable that this transformer noise is due to magnetostriction—that is, the change in length in the direction of magnetization—and it is not unlikely that the same seat is present in direct current machines, but with their combined alternating and rotating magnetization at considerably higher inductions more noise would have been expected on reduced voltage tests which have been made in order to obtain flux densities comparable with those used in transformer practice in which, in fact, we know magnetostrictive forces exist.

The chief cause of the on-load noises is the variation of the zig-zag leakage flux with the relative positions taken up by stator and rotor teeth. This is influenced considerably by the numbers of stator and rotor teeth; experience has dictated many undesirable ratios for those two quantities, but in the present state of the art there is not an infallible rule for designing a quiet motor. Designers of 20 years ago and previously always chose a prime number of rotor slots (the stator number being fixed within limits for a symmetrical winding) in order to eliminate magnetic symmetry which was thought to produce cogging and saddles. It was discovered 15 years ago that this was an unnecessary and superfluous condition and that in fact any odd number of rotor slots was in general undesirable.

There is no doubt that this question of producing silent running induction motors which have a reasonable weight for their output is a difficult

one, but progress has been and will continue to be made should the demand for such machines arise; it is of course necessary to think of the subject along with the background noise and with the technique of the reduction of the amount of noise that is transmitted.

Insulation.

The consideration of insulation must necessarily be bound up with the temperature rise. It is not necessary here to list the different Classes O, A, B and C as they are available in the various B.S. Specifications 168, 169, 170, etc. The time honored conductor coverings of single, double and triple cotton, of enamel, of silk—more recently of artificial silk—and of the various combinations of them, when used with regard to their limitations, have a successful history, as is well known.

Occasional troubles have been experienced with enamel wire but in nearly all cases this could be traced to the us of an unsuitable impregnant.

Asbestos and Lewbestos too are quite well known and suitable for the higher temperature range covered by Class B insulation.

A more recent innovation is glass covered wire, this also being a Class B material, and so far experience is good from a performance standpoint, although there is some little difficulty in handling the conductors during the winding stage, much care being needed if the glass covering is not to be damaged. Doubtless the wire manufacturers will succeed in introducing some resistance to abrasion.

Experience with the various coil insulating materials micanite, leatheroid, empire cloth, etc., has been invariably good, and it may be said that the insulation problems, as such, of the low and medium voltage machines we here have in mind are solved, but an equally important matter is the establishing of as nearly as possible a homogeneous path of low thermal resistance so that there shall be an easy passage for heat from the conductors to the iron mass which surrounds them, and which must thus dissipate part of their heat if economical design is to be achieved. We know, for example, that bitumen is very good in this respect but special plant is needed for its application. It would be advantageous if the impregnant specialist could produce one impregnant suitable at once for Class A and Class B insulations in their widest applications, and which had good heat conducting properties after forming the coil into a mass free from air instertices.

The impregnating of the conductor prior to winding and forming the coil—or impregnating simultaneously with winding—the so-called "pre-treating" or "pre-impregnating", is a matter for which the necessity would appear to be open to question. It has been asserted, and with truth, that coils wound with plain wire and subsequently impregnated have been found upon opening up and unwinding, not to have taken the impregnant at the center. But this cannot be put forward as a general truth; much depends upon the method of impregnating the coils wound with plain wire, and upon the supervisions.

During the early days of the use of pre-impregnated conductors the winding space factor was adversely affected, but with experience—and here the wire manufacturer as well as the winder of the coils is concerned—there has been found to be very little difference.

Interdependence of Some of the Previous Headings.

Long and successful experience with Class B insulation and the knowledge that machines with that insulation can be produced without any manufacturing difficulties has from time to time led to conjecture as to the desirability of a wider use of it, together with the increased temperature rise which with safety could then be used.

For marine work it would be necessary, as now, to take account of the

high ambient temperatures which exist in tropical regions, but even then if Class B were to be employed a considerable increase in temperature rise would be allowable. Such a change, however, would necessitate a thorough revision in the specifications in overload capacity in particular, and in the case of induction motors in the matter of starting torque, if the latter were expressed as a fraction of full-load torque. The fact is that the large majority of industrial and marine drives do not require the 100 per cent overload capacity in torque which is laid down in the B.S. Specification.

For a given frame the horsepower output varies, to a first approximation, as the square root of the temperature rise, and with saturated series characteristic the speed—again approximately—varies inversely as the fourth root of the temperature rise, so that the full load torque would vary as the fourth root of the cube of the temperature rise.

With shunt characteristic the full load torque would vary just a little faster than the square root of the temperature rise.

It will be seen, therefore, that machines which for the present temperature rises (Class A insulation) just contrive to develop their overload capacity—and there are many, particularly of the direct current type in which to give anything more would require larger interpoles, and of the double squirrel cage type—would not be capable of more than about 40 per cent overload in torque if fitted with Class B insulation and the temperature rise were increased to correspond.

It is important to realize that given a particular machine, it has a certain potential maximum horsepower, a certain standstill current if switched directly; it is the horsepower/time rating that we attempt to take from it that determines what percentage of full load torque it will start against, or what percentage of full load torque it will yield before breaking down, or again what percentage of full load current it will take if directly switched. There are certain refinements of secondary importance which may be made in respect of this, but in substance it remains true. Thus, for example, it is not possible to make a high speed totally enclosed machine for low temperature rise which would have anything but a short circuit current that was high in terms of full load current; but this is because the full load current is relatively small.

The efficiency and power factor of Class B machines would in general be lower, although this would depend upon the exact details; one cannot, however, but feel that for electric motor work this question of efficiency has been given too important a role. It is so seldom—fan and pump drives are excepted—that the purchaser is aware of the horsepower which should be specified that a small defection in the matter of full load efficiency is of little moment. The same argument applies to power factor. The question of reducing the constant loss in shunt characteristic machines comes under a different heading, for so long as the machine is running the fixed loss is operative, and capital expended in eliminating, say, shunt field loss is paid off probably in 10 years.

Again, the adoption of a higher temperature rise would mean the obtaining of lubricants to suit; the temperature rise itself, however, is not the real difficulty, which is the range of temperature. The range of temperature would be increased by the permitted increase in temperature rise, for provision must be made for a machine to lubricate satisfactorily when started from cold in the minimum ambient temperature.

It is the opinion of the author that where engineering prudence permits, Class B insulation with its higher temperature rises and lower overload capacities should be adopted; it is not that we are feeling in the dark, the experience is available and it would appear that it should be used. In any case the slight loss in efficiency would have to be measured, in the larger view, against the reduction in weight, which in itself saves fuel on the scale which we are discussing.

Note on a Problem in Connection with Totally Enclosed Machines.

From time to time complaints are heard about the loss of lubricant from anti-friction bearings brought about by the change in pressure as the machine heats up, and also about accumulations of condensate inside such machines. This later problem is not confined to electrical machinery. The two problems are in part related, although a complete solution to the former would alleviate but not eliminate the latter. An idea incorporating a floating piston has been considered. (Prov. Patent 4555, March, 1944) and in connection with this an investigation was made of which some facts which are likely to be of interest are given here. In the average end shield type of motor, some 50 to 75 per cent of the internal volume is air, and if we assume airtightness within the pressure range, there would result for unchanged volume and the temperature rise of the internal air experienced in practice, a pressure increase of something less than half an atmosphere, or alternatively, if total relief from pressure increase is required, an expansion chamber having a volume of from 10 to 20 per cent of the machine volume.

A standard machine totally enclosed, fitted with ball and roller bearings and ordinary grease baffles, was first experimented on. It was found impossible to develop even a fraction of the anticipated pressure, but grease was expelled during heating up, the temperature being much higher than normal. All clearances were then sealed with a sealing paint and the machine was heated up at standstill. The pressure increased almost exponentially with time for the first 40 minutes to about 6 inches of water at which conditions one of the bearing (paint) seals failed, the pressure dropping to about half an inch of water nothwithstanding that the temperature had increased to more than three times that at which it was when maximum pressure was attained. The subject has had further time spent on it but the results are not ready for publication. Figure 11 gives an idea of the preliminary results.

Alternating Current Drive for Auxiliary Machinery.

There is no doubt that in the very near future serious consideration will have to be given to the adoption of alternating current for ships' auxiliaries. The distribution of three phase alternating current for the same voltage stress is cheaper in capital outlay and more efficient and the squirrel cage motor is probably the most reliable and most robust to be found anywhere.

There are, however, conditions to be met in marine applications which themselves require very careful thought along with certain limitations of the more robust types of alternating current motor.

One of the first vessels in Europe, if not the very first, in which alternating current motors were used largely for auxiliaries was the Hamburg-Amerika Line 6800 Shp. cargo vessel *Wuppertal*. In this case direct current machines were used only for the deck auxiliaries. There is a good deal of experience available from the U.S. Navy, and some three years ago Lieutenant Commander Rickover gave a most interesting paper to the American Society of Naval Architects and Marine Engineers. In an analysis of battleship auxiliaries he gives 85 per cent of the installed horsepower as being single speed squirrel cage machines, 9.6 per cent as multi-speed squirrel cage machines, together with the statement that wound rotor machines are used for winches, capstans, cranes and similar equipment.

The conditions, of course, are not quite the same. For example, some 8½ per cent of the total number of motors, representing about 35 per cent of the total auxiliary horsepower of 10,900, is concerned with 16 inch gun turrets and ammunition handling, and the total of motors employed

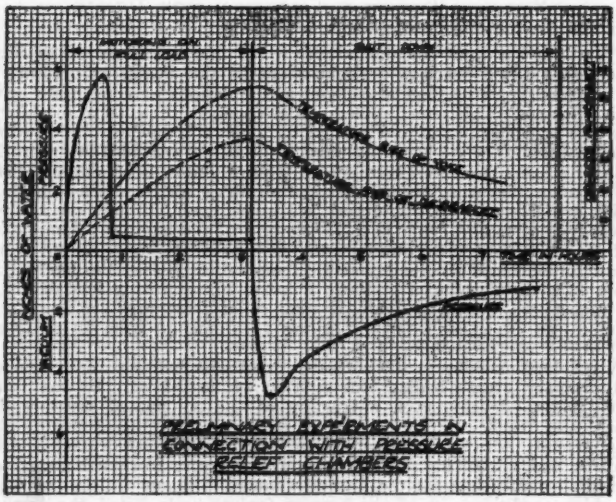


Fig. 11.

in connection with gunnery and ammunition handling is some 20 per cent of the whole number and almost 50 per cent of the total horsepower.

It is known that marine engineers have their views on this problem of alternating current auxiliaries and it is not the purpose of this paper to persuade them one way or the other. This can be said, however, that given details of a particular case it is possible to arrive at a decision free from ambiguity, and in arriving at this decision it would not be necessary to take account of any difference in maintenance charges.

Unquestionably, one of the main problems with A.C. drive would be the performance of the winches and capstans, and two or three solutions have been under consideration.

Types of Polyphase Altering Current Motor which Might be Used for the Drive of Auxiliary Machinery.

The ordinary polyphase induction motors designed for continuous operation has, as has already been stated, a shunt characteristic. On light load its speed for all practical purposes is synchronism, and as the load is increased the speed falls away in almost a linear manner to some 5 per cent below synchronism at full load, and then decreases at a slightly faster rate to just below maximum torque, where, of course, it has a turning point. The machine is therefore essentially a constant speed one in its elementary form. The synchronous speed is proportional to the frequency and inversely proportional to number of poles. It so happens that the distributed winding with which the stator of an induction motor is provided is especially suited to be adapted for different numbers of poles. With very little switching complication an "N" pole motor can be reconnected for "2N" poles, and by incorporating two such pole-change windings in the one motor it is possible to obtain N, 1.5N, 2N, and 3N poles. It is also possible by suitable choice of the stator slots to incor-

porate four separate windings corresponding to any numbers of poles. This use of separate stator windings is useful when separate control of the connection of the two windings is required, and it also serves when a two speed motor whose pole ratio is not two to one is required without complicated control gear; this would be a case in which the size of the motor was increased in order to cheapen the control of the machine. Wound rotor motors are rather difficult to arrange for pole numbers greater than two and in fact this may be said to be impracticable. The design of a squirrel cage rotor for use with a change-pole stator is a compromise, but many successful motors are in operation; much depends upon the starting performance required and upon the method of starting.

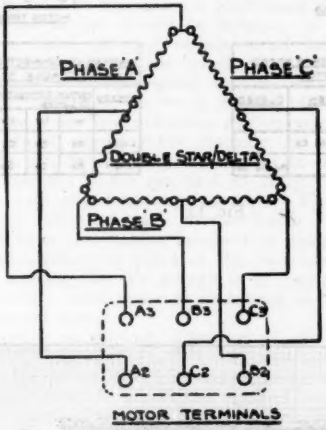
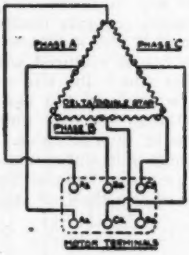


DIAGRAM OF CONNECTIONS FOR 2-SPEED CONSTANT HORSE POWER S.C. MOTOR.

SPEEDS	MOTOR CONNECTIONS TO LINES.			OPEN	CLOSED
	L1	L2	L3		
LOW	A2	C2	B2		A3 B3 C3
HIGH	A3	B3	C3	A2 B2 C2	

FIG. 12.

The stator coil span on pole change motors generally is arranged to be full pitch on the greater number of poles, with the result that it is 50 per cent chorded on the half number of poles, the phase groups being reconnected in order that the flux per pole and magnetizing current shall have suitable values for the duty. In this respect constant torque motors are not reconnected in the same way as constant horsepower machines. Figures 12 and 13 show typical methods, but there are other ways of accomplishing the object, and also in some cases the stator winding is



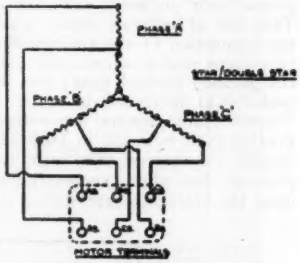


DIAGRAM OF CONNECTIONS FOR 2 SPEED CONSTANT TORQUE AC MOTOR.

SPEED	MOTOR CONNECTIONS TO LINES			OPEN	CLOSED
	L1	L2	L3		
LOW	A2	B2	C2	A2 B2 C2	
HIGH	A1	C1	B1		A1 B1 C1

DIAGRAM OF CONNECTIONS FOR 2 SPEED VARIABLE TORQUE AC MOTOR.

SPEED	MOTOR CONNECTIONS TO LINES			OPEN	SHORTED
	L1	L2	L3		
LOW	A2	B2	C2	A2 B2 C2	
HIGH	A2	C2	B2		A2 B2 C2

FIG. 13

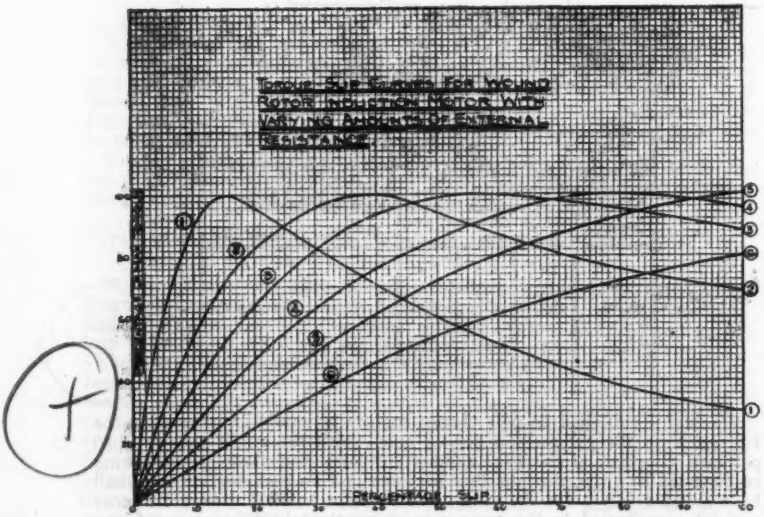


FIG 14

not pitched full on the greater number of poles. But these details belong properly to the design of the machine.

It will be seen that the pole-change motor is a change speed machine, but not a variable speed motor. A wound rotor machine with variable external rotor resistance can be arranged as a variable speed machine, but unless the opposing torque-speed function is known with certainty the arrangement is not an Ideal one because of the variation of speed with torque at the same resistance setting. In order to make provision for lack of knowledge of the exact torque-speed relation of the load, these external rotor regulators frequently have to be made considerably larger than they need be; on the one hand the resistance must be large enough in value to obtain the desired speed reduction with a torque less than that which exists, and on the other it must have excess current carrying capacity in case the torque should be heavier. A wound rotor machine operating with a fixed external resistance of suitable value will give a torque-speed curve suitable for winch work, but the arrangement is wasteful of energy. Torque-speed curves with different values of external rotor resistance are shown in Figure 14.

It is possible by using two induction motors mechanically coupled, one of which must be a wound rotor machine, to obtain a change speed machine characteristic by coupling the motors in cascade. The stator of one motor is connected to the line and its rotor feeds the stator of the second machine with clip frequency currents. The possible speeds here are those corresponding to each motor (with the other disconnected electrically) and to motors having numbers of poles equal to the sum and difference of the numbers of poles of the two motors. It will be noted that instead of wasting the slip energy in a resistance as is done in the wound rotor machine with external resistance in the rotor circuit, it is utilized in the second motor.

A further example of efficient utilization of slip energy is the Kramer system, in which the slip energy is fed into the slip rings of a synchronous converter which supplies a direct current auxiliary motor. In this system it is conveniently possible to adjust the power factor favorably.

The polyphase shunt characteristic commutator motor is a true variable speed machine and with the improvements that have been made in its commutating properties will demand consideration. It is, however, felt that where possible the superintending engineer will desire to eliminate commutators; some have indeed expressed the view that they do not like the idea of "commutators on alternating current". It is necessary to bear in mind that the periodicity of supply is very low in terms of the periodicity of commutation, and that there is nothing wrong with alternating current *per se*. At the same time, judged by some of the standards of alternating current commutation of the past, there is something to be said for the cautionary attitude.

There is nothing complicated about the shunt commutator motor. Consider a wound rotor machine operating say, at 50 per cent slip with external resistance; to a first approximation the external resistance has half the rotor standstill voltage across it, and the frequency is half that of the line. For any other speed the voltage across the external resistance would be the standstill rotor voltage multiplied by the fractional slip, and the frequency would be that of the line multiplied by the same factor. Now, if we could arrange to inject such a voltage at the correct frequency into the rotor circuit, it is clear that we could constrain the rotor to run at the corresponding speed without the waste of energy in the rotor circuit resistance. The great difficulty at first sight is in arranging to vary the voltage and frequency with every change in load and speed so that it corresponds with the new conditions; obviously it could not be done by hand even if one could by conceivable means contrive to vary the frequency. This is where the commutator comes into use. A commutator

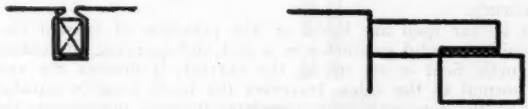
is fundamentally a frequency converter; thus, in the direct current machine it achieves complete rectification of the alternating current in the armature conductors. If we could arrange to rotate the brush gear of a direct current generator at the same speed as the armature in the same direction and tap from the brush arms by means of slip rings, it is clear that the machine has been converted into an unorthodox form of alternator—one in fact in which the commutator and brush gear are superfluous. If the speed of rotation of the brush gear were now halved, the frequency of the current picked up by the slip rings would be half the fundamental frequency of the machine, and so on. Now in rotor fed type of shunt commutator motor (the Schrage machine) the currents in the commutator winding always have line frequency; they are, in fact, induced by transformer action from the primary winding which lies in the same slots below it. Utilizing the same argument the current led away from the commutator brushes always has slip frequency. The speed of the motor is controlled by applying to the secondary winding varying voltages obtained by opening two brush halves which allow in effect varying amounts of the commutator winding to apply their voltage to the secondary. The shunt commutator motor is therefore in principle an induction motor and it has in fact most of its characteristics except in the regenerating zone. At synchronism the commutator winding feeds direct current to the secondary winding, and by further reversing the brush halves the machine can be taken to supersynchronous speeds; in reversing the separation of the brush halves we reverse the phase of the injected Emf. The speed control can be made from a distance by means of a pilot motor and gear box. Speed control entails brush movement and it has been said against these motors that in consequence the brushes do not get properly bedded. This of course is largely governed by the workmanship of the brush boxes.

The stator fed motor has the primary winding housed on the stator, but the frequency change idea and injection idea are identical with those discussed except that the voltage injected is obtained from an induction regulator fed from the line. In this type of machine the commutator brushes remain stationary, and the fact that the primary winding is housed on the stator enables it to be wound directly for higher voltages than the rotor-fed machine, the primary of which must be fed through slip rings.

For constant speed drives there is the synchronous-induction motor which is started as an induction motor with rotor resistance and then synchronized when it attains speed by switching an exciter, direct coupled to the motor, into the rotor circuit. The power factor of the motor can then be improved by adjustment of the excitation. This illustrates the use of a direct current exciter for improving the power factor, but it is possible to use a wound rotor induction motor with an alternating current exciter—or as it is termed, a phase advancer—for exactly the same purpose. Each has a commutator, but it would appear that the induction type synchronous motor with direct current exciter is the more popular. The methods of connecting the rotor winding of the synchronous induction motor for supply by direct current are many and varied and a description of these, together with a discussion of some points in connection with this very interesting machine, will be found in Rawcliffe's paper[18].

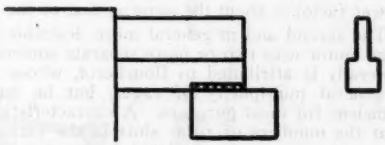
High Starting Torque Squirrel Cage Motors.

The normal squirrel cage motor is at a disadvantage when it has to start against an appreciable torque. The average machine requires from three and a half to five times full load current in order to yield full load torque, and in order to reduce the amount of voltage variation consequent upon drawing such currents public supply authorities have in the past only allowed comparatively small sizes of squirrel cage motors. In passenger boats some of the conditions that led to the framing of the regulations would hold good.



ⓐ ORDINARY SQUIRREL CAGE.

ⓑ DEEP BAR SQUIRREL CAGE.



ⓒ SHAPED BAR FOR HIGH TORQUE.

FIG. 15.—*Comparison of ordinary and high torque rotor conductors.*

In any case there are available special types of squirrel cage motor which give considerably improved starting performance. The starting torque is proportional to the rotor circuit loss at switching; in consequence, a wound rotor machine may be made to give any torque at starting of which it is capable, simply by arranging for a suitable value a rotor resistance. But we do not then have the simplicity of the squirrel cage.

The problem then in the design of a high torque squirrel cage motor is that of arranging somehow to get a large rotor copper loss at starting and a normal one when running, this latter first on the score of heating, secondly on efficiency.

All the ideas so far used are based on the principle of current displacement. Consider a solid conductor in a slot and carrying alternating current; a magnetic field is set up by the current, it crosses the slot approximately normal to the sides, traverses the tooth roughly parallel with the depth of the conductor, and completes its path underneath the slot. Now it is apparent that if we consider strata of the conductor proceeding upwards from the base of the slot, the strip at the bottom of the slot will be linked with more magnetic lines than the one just above it and so on. This results in the portion of the conductor nearer the bottom of the slot having greater inductance than those nearer the top, in consequence the current is driven towards the top of the slot and the apparent resistance of the conductor is considerably higher than its direct current resistance. The reactance associated with this inductance is proportional to frequency, and when the induction motor is switched, the rotor and line frequencies are equal, the rotor frequency decreasing to a very low value when the machine has accelerated. Hence this displacement of rotor bar current depends upon the slip being a maximum at standstill and giving maximum rotor copper loss, and decreasing gradually, resulting in normal copper loss at full load.

The disadvantages of the deep bar rotor are (1) that due to the design requiring a deep, and consequently narrow slot, the full load power factor is affected adversely, (2) the accelerating performance is sensitive to any field harmonics, and (3) the squirrel cage is not so easy to construct as the more orthodox design.

A variation of the deep bar rotor uses a special shape of slot conductor which facilitates construction (Figure 15) and which does not require quite so deep a slot, but for the same percentage starting torque the power factor is about the same as that of the deep bar conventional design.

The second and in general more desirable class of high torque squirrel cage motor uses two or more separate squirrel cages. The basic invention generally is attributed to Boucherot, whose original design provided for a general multiplicity of cages, but he quickly found that two were sufficient for most purposes. A characteristic of the Boucherot rotor was that the numbers of rotor slots in the various cages were equal, that is, the cages were accommodated as it were in one set of specially shaped and elongated slots. The number of joints between bars and rings was therefore $2nm$ where n is the number of rotor slots, and m the number of cages.

Shortly after the 1914/18 war, a Dutch firm[19] introduced an important modification to the original Boucherot idea. The performance of these motors is profoundly influenced by the ratio of reactance to resistance of the separate cages, as well as by relation to each other, and it was found that a very favorable ratio of reactance to resistance for the running cage could be obtained by making the number of slots of the inner (running) cage a sub-multiple of that of the starting or outer cage. This at once reduced the number of inner cage joints, reduced the rotor saturation and generally made a more desirable motor. It has been largely used, and compared with the deep bar rotor has a much better full load power factor.

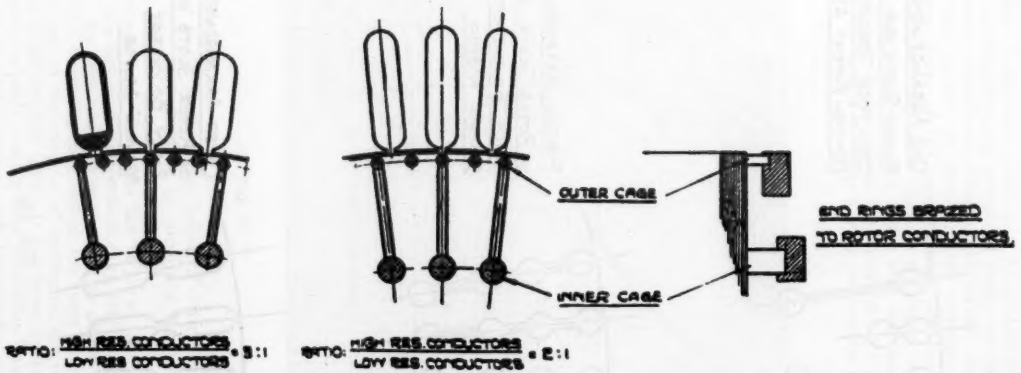
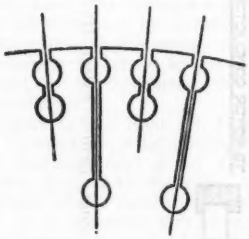
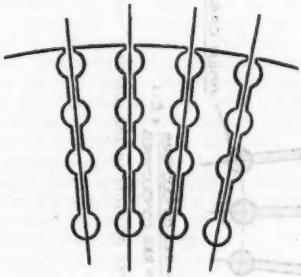

OUTER CAGE
INNER CAGE
END RINGS BRAZED
TO ROTOR CONDUCTORS.
RATIO: HIGH RES. CONDUCTORS / LOW RES CONDUCTORS = 3:1
RATIO: HIGH RES. CONDUCTORS / LOW RES. CONDUCTORS = 2:1

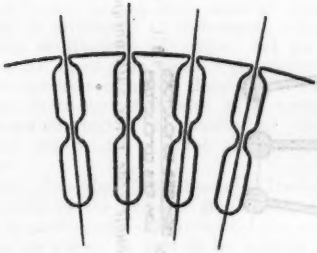
FIG. 16A.—*Double cage rotor with unequal numbers of slots in the starting and running cages, British patent 179,890(1923).*



ONE ARRANGEMENT OF ROTOR SLOTS FOR THREE DECK HIGH TORQUE MOTOR (BRITISH PATENT 494660)



TYPICAL ARRANGEMENT OF ROTOR SLOTS IN EARLY BOUCHEROT "GAMMA" MOTOR.



LATER ARRANGEMENT OF ROTOR SLOTS IN EARLY BOUCHEROT "GAMMA" MOTOR

FIG. 16B.

The principle of operation follows directly from the explanation of the deep bar rotor, except that here we consider separate cages instead of imaginary strata of the one conductor. At switching the running cage, which has low resistance and is embedded deeply in the iron so as to give it high inductance, contributes little to the torque, the lower impedance of the outer cage—despite its much higher resistance—ensuring that it takes the greater share of the ampere-turns. As the motor accelerates, current changes from the outer cage to the inner cage because of the reactance becoming a less dominant factor with the reduction in secondary frequency. Little is known about the more obscure phenomena of this double cage motor and it presents a very fascinating field for study and research.

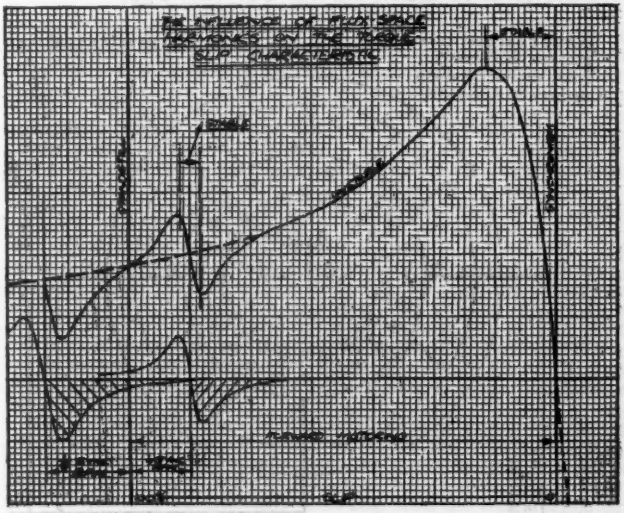


FIG. 17.

A little prior to the present war, Schwarz[20] introduced a modification of the simple double cage machine by providing the running winding with positive pitch turns.

Sets of slots on three diameters are required, and a unit of the inner cage occupies one slot on the lowermost cage, returning in the intermediate row of slots. By this means it is possible to obtain a definite pitch for the elements of the running cage, and at the same time half the number of joints on that cage at the expense of employing specially bent conductors instead of the usual straight bars. It has been claimed that the employment of the positive pitch running cage eliminates "marked troughs" from the accelerating characteristic; it will perhaps be of interest to discuss briefly the origin of such troughs. The rotating magnetic field of the commercial polyphase induction motor contains harmonics in the flux-space wave. Even harmonics are not present due to symmetry, and in a three phase machine the seventh and ninth harmonics have the same rota-

tion as the fundamental, the third and fifth are negative. Moreover, the third and its multiples are single phase torques, that is they give zero torque at their own standstill.

In practice, the seventh harmonic has given most trouble, and its effects may be examined by imagining it to be replaced by a separate small motor having seven times the fundamental number of poles. It has a speed torque curve of the usual induction motor family, and this is superimposed on the fundamental curve at one seventh of synchronism. The negative portion of the seventh multiple field subtracts its torque from that of the fundamental and there is in consequence a dip or trough in the resultant

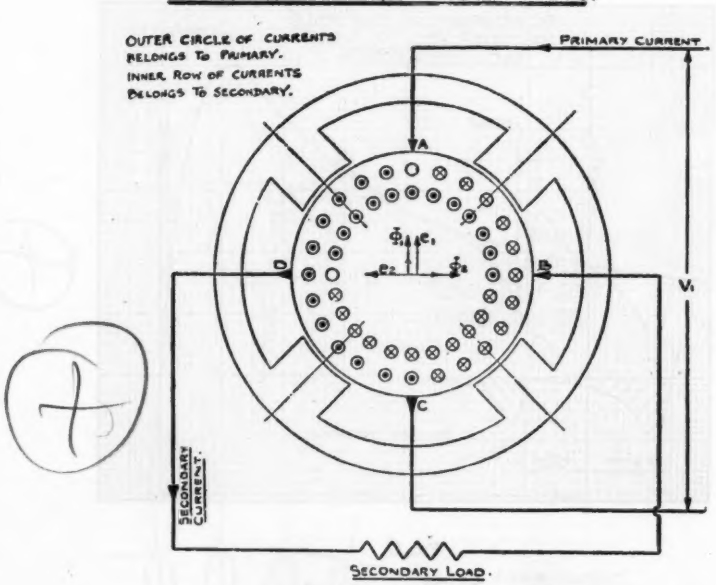


FIG. 18.

curve. If the minimum resultant torque at this speed is less than the opposing torque the machine will not accelerate, and is described as "crawling on the seventh harmonic".

Now in order to obtain a good full load efficiency, the ratio of resistances of the inner and outer cages of a double squirrel cage motor must be such that at one seventh of synchronous speed the ratio of the torque developed by the inner cage to that developed by the outer varies from about one eighth to one sixth, so that to obtain measurable improvement in interaction with the seventh flux harmonic it is the outer cage, not the inner, which should be positively pitched.

A very superficial treatment of some of the characteristics of the more orthodox types of machines has been attempted, and it has been thought

unnecessary by the nature of the paper to attempt to give credit to everyone who has done work in one or other of the fields.

In conclusion a return will be made to the sphere of direct current in order to make mention of two systems of control. The first is the metadyne[21], which is a cross field machine usually employed to convert power at constant voltage to power at constant current. By a cross field machine is meant one which is excited fundamentally by the armature magnetomotive force; field windings are fitted to the metadyne in practice but only with the object of controlling the characteristic.

With reference to Figure 18, let the throw of the armature conductors be such that when current is led in at A and out at C, the distribution of the armature current sheets will be as there shown. A two pole magnetic field will be established in the upward direction. If now the armature is rotated by external means, an Emf. will be generated by the cutting of that flux by the conductors which set it up. The axis of collection of that Emf. will be electrically (and in this case geometrically) at right angles to the axis of the original current sheet. Let the points of collection B and D be joined by an external circuit which will be called the secondary. It can be proved that if A is positive then (for the throw of the conductors which gives rise to the flux shown) so will D be positive. Current flows then, from D to B, and inside the armature will be superimposed on the primary current led in at A. For purposes of explanation there will be imagined a second set of armature conductors, and they will have a current distribution as shown. This system of currents will set up a magnetic flux having the direction D to B, and the rotation of the conductors in that flux will give rise to an Emf. acting from C to A, i.e. the back Emf. of the metadyne. It will be seen that stability is achieved, because any tendency for the secondary current to increase will result in a greater secondary flux and back Emf., thus reducing the primary current and in turn the primary flux and secondary voltage. Figure 19 shows primary volts and current, and secondary voltage and current plotted as functions of the power input, neglecting losses. The shape of these curves can be altered considerably by biasing the flux set up by the armature magnetomotive force from an external source by means of field windings housed on salient poles.

It is convenient to describe the metadyne as a so many cycle machine rather than by the number of poles. Thus the practical form of the elementary machine described would be a single cycle machine. The armature would be wound for two poles, but there would be four main polar projections, and possibly, depending upon the commutation factors, four interpoles.

The control of the characteristic may for example be made by setting up a flux along the axis BD in opposition to the secondary Mmf. Since the flux resulting must remain constant, the armature draws a current to compensate for the action of the variator winding; this upsets the torque balance and it is necessary to fit a further set of coils known as the regulator winding and set up an Mmf. in opposition to the primary.

It will be seen that the metadyne forms a convenient type of motor booster. It is the invention of Professor Pestarini, but much of the credit for its development must be given to the Metropolitan Vickers Electrical Co., Ltd., who quickly saw its possibilities in electric traction. A much smoother starting performance is obtained than with the conventional resistances and contactors, and the starting efficiency is much higher. It would appear that its economical application is not limited to traction work or marine propulsion.

Booster Control.

Closely related to the performance of the metadyne is that of booster control[22] of direct current motors. There are occasions in which a booster

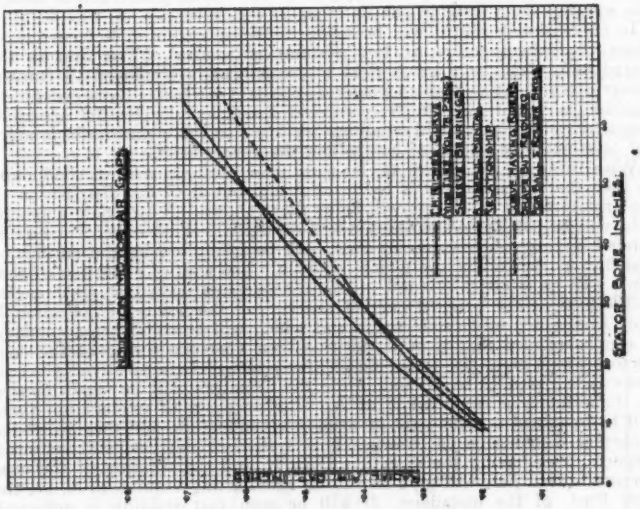


FIG. 20.

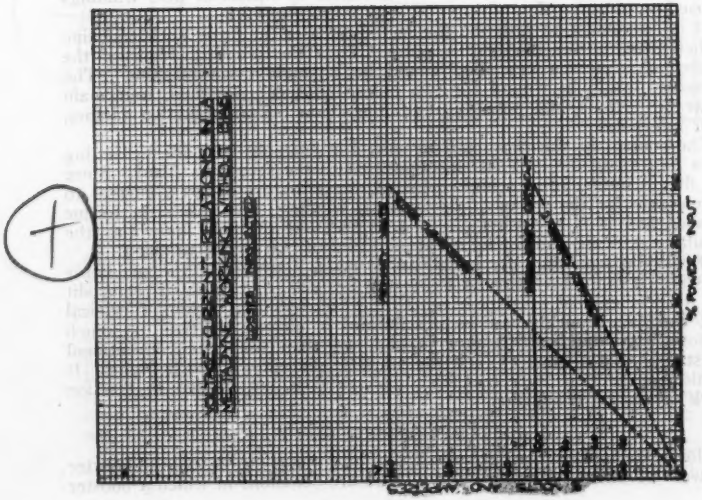


FIG. 19.

controlled motor is the only solution to a drive without resorting to very special construction, but as a general rule the application is to obtain a particular performance. Very smooth control can be obtained in a variety of ways, and for the majority of marine applications true booster control is cheaper than Ward Leonard control because in the latter the output of the motor generator set must be capable of supplying the full load output of the main motor. The motor generator can be reduced in size by running it at high speed, but this applies with equal force to the motor booster in the booster control type, since however the booster can be arranged to boost or oppose the main motor, other things being equal it will have only half the capacity of the Ward Leonard motor generator performing the same duty. The booster control system, however, requires in general more expensive switchgear than does the Ward Leonard system because in the latter reversal of the main motor rotation can be made simply by reversing the field of the generator supplying it.

BIBLIOGRAPHY

[1]"Series Stability Windings and their Dependence upon the Working Flux". R. S. Blackledge. *Journal I.E.E.*, Vol. 89, Part 1, p. 291.

[2]"Heat Paths in Electrical Machinery". Symons and Walker. *Journal I.E.E.*, Vol. 48.

[3]"The Cooling of Electrical Machinery". D. B. Hoseason. *Journal I.E.E.*, Vol. 69, p. 121.

[4]"Eddy Currents in Large Slot Wound Conductors". A. B. Field. Transactions American I.E.E., Vol. 14, p. 761.

[5]"Idle Currents". M. B. Field. *Journal I.E.E.*, Vol. 37, p. 83.

[6]"Heat Losses Due to Load Current in Direct Current Armature Windings". E. A. Hanney. *Journal I.E.E.*, Vol. 71, p. 263.

[7]Ottenstein's German work is abstracted in Volume 2 of *The Dynamo*, by C. C. Hawkins, p. 709 *et seq.*, 5th edition.

[8]Electrical Engineering Papers. B. G. Lamme. (Westinghouse Manfg. Co.).

[9]"Diagnosing of Troubles in Electrical Machinery". Miles Walker, p. 92.

[10]Pole Face Losses Due to Open Slots". Professor K. Aston and K. Rao. *Journal I.E.E.*, Vol. 88, Part 1, p. 308.

[11]"Measurement of Stray Load Loss in Polyphase Induction Motors". C. J. Koch. Transactions American I.E.E., 1932, p. 756.

[12]British Patent Specification No. 462,974 (1937), Benno Schwarz.

[13]British Patent Specification No. 518,047 (1940), The British Thomson-Houston Co., Ltd.

[14]"Treatise on the Theory of Elasticity". A. E. H. Love, Vol. 2, p. 257.

[15]"Mechanical Vibrations". Den Hartog.

[16]"Vibration Problems in Engineering". S. Timoshenko.

[17]"Magnetic Noise in Dynamo-electric Machines". F. W. Carter. British Association Section G 1932. *Engineering*, Nov. 4 and 11, 1932.

[18]"The Secondary Circuits of Synchronous Induction Motors". G. H. Rawcliffe. *Journal I.E.E.*, Vol. 87, p. 282.

[19]British Patent Specification 179,890 (1923) Naamlooze Vennootschap Hengelosche Electrische en Mechanische Apparatenfabriek.

[20]"British Patent Specification 494,660 (1938). Dr. Benno Schwarz.

[21]"The Metadyne, and Its Application to Electric Traction. G. H. Fletcher and A. Tustin. *Journal I.E.E.*, Vol. 85, p. 370.

[22]"Booster Control Instead of Shunt Field Control". R. S. Blackledge. *Mining Electrical Engineer*, Vol. 18, p. 119.

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

EXAMINING TUBES FOR CORROSION.—An article by G. H. Stanley on "Some Cases of Corrosion in Engineering Practice" in a recent issue of the *Journal of the South African Institution of Engineers,* describes the methods used by the author for examining corrosion pitting on the inner surfaces of oil cooler tubes. Visual inspection of the wet dirty tubes when illuminated from the other end proved to be of very doubtful value, and even after hosing through with clean water, it was not possible to correlate the results with the results of inspection of the tubes when subsequently split. The author states that "probing" by means of a forked probe made of spring steel wire (see Figure 1) made it possible to locate

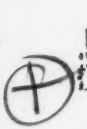


FIG. 1.—*Tube probe.*

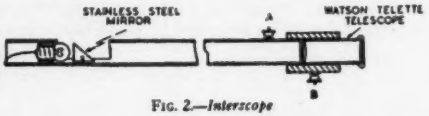
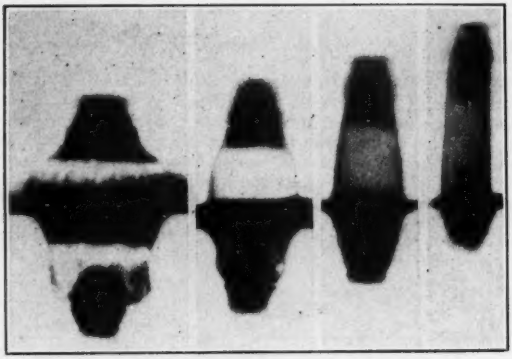
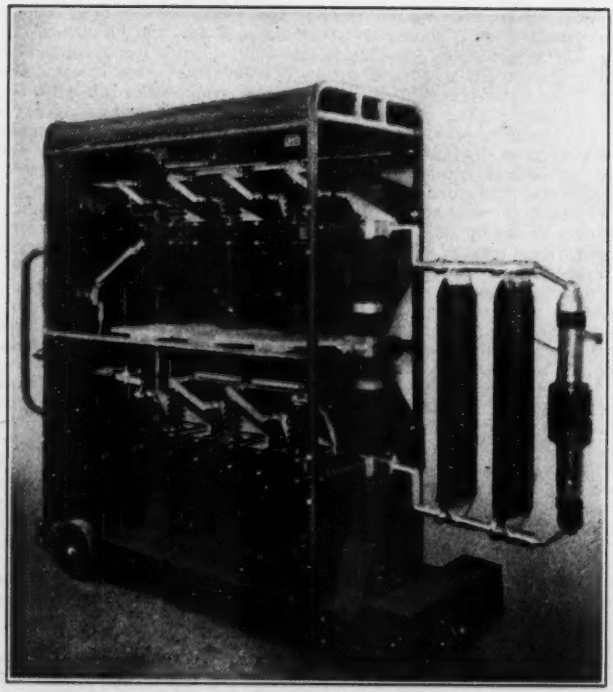


FIG. 2.—*Interscope*

the pits and to form some idea of their depth and extent. After the tubes had been cleaned and dried, a close examination of the doubtful spots was carried out with a home-made "interscope", the construction of which is shown in Figure 2. A 4-foot length of ½-inch copper tubing of ⅜-inch internal bore was thinned down by filing it on the outside until it would enter the tubes under examination. A 2.5-volt electric torch bulb was suitably mounted and inserted at one end so as to illuminate the spot examined through an aperture in the wall of the copper tube. A small mirror was adjustably mounted just in front of the bulb so as to reflect the image of any spot under examination to the other end of the tube, where a small telescope was fitted in a bakelite sleeve which served as an eye-piece. Connection to the lamp was made by the tube itself and by an insulated lead in a groove milled out of the tube wall, to which terminals A and B were respectively connected. The requisite current was provided by dry cells which were connected to these terminals. A draw-back of this interscope was the fact that it was rendered temporarily useless if the tube was so wet as to foul the mirror. Many tubes were examined *in situ* by means of these two devices, and as the great majority of them appeared to be in good condition, the corrosion which had occurred in the others was attributed to untoward surface conditions, since the composition and micro-structure of the tube metal was similar. A number of spare tubes in store were likewise examined by the interscope. All of these appeared to have been heated at the ends, possibly for annealing, and they had probably been subsequently cooled by plunging into a trough of water covered by floating scum or dirt. The resulting ebullition caused splashing and deposits of black spots, and sometimes more or less complete coatings of dirt, which "dried on" and became difficult to remove; internal brushing of the surfaces produced small particles of grit with a few copper and brass filings, together with traces of sawdust and a little oily matter. Several tubes also showed mechanical defects in the form of scores, roughness and porous patches, as well as a few long irregular grooves—possibly caused by long drawn-out blisters. As regards this last form of defect, similar blemishes were observed in some tubes in use, and in a few instances actual pieces of scale or films of copper were detached from their surfaces by means of the probe. A careful re-examination of all the perforated tubes thereupon revealed the formation of extensive black (varnish) scale in nearly every case, whereas uncorroded tubes from the oil cooler opened for examination showed, with one



A Series of X-Rays of a Shell Piercing Armor Plate, each taken in a Millionth of a Second. It Discloses that the Shell Swells to nearly Twice Size before Bursting.



The High-Speed X-Ray Machine Consists of a Bank of Capacitors that Discharge through a Special Tube, at the Extreme Right.

exception, only a smooth olive-green patina. Lines of corrosion product were frequent on draw marks covered by scale, and spots were also observed at the termination of the draw marks, as if the pitting had been caused by the embedded particles responsible for the draw marks. A comparison of the corroded and non-corroded tubes and of corroded and non-corroded portions of the same tubes showed quite clearly that corrosion and pitting were more liable to occur where the surfaces had been rough originally, such roughening being the result of the removal of oxide scale subsequent to manufacture. The author declares that these observations, as well as the results of various experiments which he made, point to the fact that the pitting which developed in these tubes was caused, in the first instance, by surface defects, such as small pores or pin-holes, deep drawn lines, specks of included foreign matter, e.g., grit, scale or even abraded metal from the drawing appliances, oxide scale not removed by pickling and more or less cracked or porous, and splashes of scum from dirty water during manufacture or storage. No single one of these blemishes may have been sufficient to start a pit, except perhaps certain pores or pin-holes, but some unfavorable concurrence of circumstances at a defect, e.g., at the edge of a dirty water spot intersecting a deep draw line on an oxidized surface, causing the formation of a pustule or blister which grows with rapid pitting underneath. A speck of iron which oxidizes quickly produces a pustule, small hole or crack in an otherwise continuous coating of oxide scale and constitutes a small anodic surface, with similar results. The author concludes by emphasizing the need for greater care on the part of tube manufacturers in order to eliminate the occurence of surface defects and to ensure the complete removal of oxide scale during the pickling process. Every care should also be taken to make certain that the tubes go into service with clean inner surfaces.—*"Mechanical World", Vol. 116, No. 3,011, 15th September, 1944, p. 299.*

X-RAY PICTURES IN A MILLIONTH OF A SECOND.—One tool important in this war uses more power than the city of St. Louis, costs more to run than the war itself, and has a total life of one thousandth of a second. It is a high-speed x-ray unit, capable of making pictures in a time as short as one millionth of a second. For such a picture an enromous burst of power is released through the tube, about 2000 amperes at 300 Kv., which is 600,000 Kw. for a microsecond. Although a single picture costs only a dollar, that sum is spent at the rate of 3.6 billion dollars per hour. The tube can be used a thousand times; but, because each exposure lasts only a millionth of a second, the total service life of the tube is only a small part of a second.

Most obvious use of such high-speed x-raying is in ballistic studies. A great deal of pioneer work in this field has been done at Frankford Arsenal. It has been used there to determine the location of a projectile in a gun barrel with respect to the curve of gas pressure versus time. The effects of the rapid acceleration on the component parts of composite projectiles such as explosive bullets, and the manner of progression of a projectile through armor can be similarly recorded. Pictures of actual penetration taken by ordinary high-speed photographic means are obscured by luminous fragments created by projectile impact.

Such high-speed x-ray pictures are expected to have many non-military uses such as studies of rapid chemical reaction, the movements of valves, springs, and cams of engines.

The high-speed x-ray machine, surprisingly enough, is extremely simple —in many ways simpler than the ordinary type. A surge generator is charged slowly and then suddenly discharged through a high-vacuum tube. The tube is of special design to utilize the short pulse of a large amount of energy to produce x-radiation of abnormally high intensity.

The fact that the power is stored in capacitors suggests another use for the apparatus. The energy, if discharged as an arc in air instead of through the tube, provides the excellent short-lived but intense illumination required for ordinary high-speed spark photographic work, thereby eliminating the need for a high-speed shutter. Thus the device can be used either for taking high-speed x-ray picturs or as a light source for ordinary high-speed pictures.

SILICONE RUBBER—*Bouncing Putty*—Silicones—curious compounds of silicon—had been previously announced as resins, oils, insulations, and water-repellents, with important wartime applications. Startling new silicones have now been evolved in the Research Laboratory—silicone rubbers, which retain their elastic properties at temperatures from —60 to 575 F; natural rubber is brittle and smashes like glass at the low temperature, and melts or burns before reaching the higher temperature. The turbosuperchargers of the B-29 Superfortress and Navy searchlights incorporate gaskets of silicone rubber.

The gaskets in both of these applications must be able to withstand high temperatures. Natural rubber will not do so; synthetic rubbers became hard and brittle after 100 hours of operation at 300 F. A gasket of silicone rubber, even after operating continuously for 300 hours, was still soft and could be used again. This is due to its lack of "compression set" at high temperatures. Compressed between metal plates to two-thirds its original thickness and held for several hours at 300 F, it will when released return to 90 per cent of its original dimensions.

One curious form of silicone rubber is "bouncing putty." It can be kneaded and pulled like putty, but when rolled into a ball it bounces like rubber. It is both elastic and plastic, and which of the properties it exhibits depends on the rate at which stress is applied. Struck sharply, it is rubbery; squeezed slowly, it is putty-like.

Silicon, present in sand and glass, is a close relative of carbon. Both elements can form long chain-like molecules called polymers. Organic polymers, such as natural and synthetic rubber, have as a backbone a string of carbon atoms. Silicone rubber is also a polymer, but its backbone is a series of units each consisting of a silicon and oxygen atom. This replacement of the carbon backbone with silicon-oxygen linkages is responsible in most instances for improved thermal stability .

BOOK REVIEW.

AMERICAN MARINE DIESEL ENGINES, BY LOUIS R. FORD, EDITOR OF "MOTORSHIP." PUBLISHED BY DIESEL PUBLICATIONS, INC., 192 LEXINGTON AVENUE, NEW YORK, 16, N Y. LIST PRICE $1.75 IN THE UNITED STATES, $2.25 ELSEWHERE.

A 280 page, pocket size, paper covered book, with 116 illustrations, which describes the details of design and construction of 16 different American marine diesel engines built by 12 different manufacturers. This is a collection of articles intended for the operating engineer which have previously been published in the magazines "Motorship" and "Diesel Power." Important maintenance features, clearance data, pressure and temperature data are included for each engine, as well as descriptions of the valve gear, fuel, lubrication and cooling systems, and the control gear.

ASSOCIATION NOTES

The Council of the Society held a meeting in Washington on 29 March, 1945, to discuss routine business.

Addresses.

Present conditions make it most difficult to ensure prompt delivery of Journals. It is earnestly requested that members report promptly all changes in address.

Membership.

The following have joined the Society since the publication of the February, 1945, Journal:

Naval.

Akerson, C. B., Ensign, U. S. N. R.

Aldrich, Harold L., Lieut. Commander., U. S. N. R.,
Code MST, Norfolk Navy Yard, Portsmouth, Va.

Angel, Theodore James, Lieut., U. S. N. R.

Ash, Robert S., Lieut., U. S. N. R.,
Asst. Ind. Mgr., care Globe S. B. Co., Superior, Wis.

Beene, Dudley C., Lieut., U. S. N. R.,
Room 137, Bldg. 633, Naval Air Station, Pensacola, Fla.

Bentson, Edwin Lewis, Ensign, U. S. N. R.

Berner, George A., Lieut., U. S. N.,
442 Esplanade, Pelham Manor, N. Y.

Bomba, William Joseph, Lieut., U. S. N. R.

Boyd, Gordon H., Lieut., U. S. N. R.,
224 Brookline Boulevard, Upper Darby, Pa.

Brock, John F., Machinist, U. S. N.

Brooks, D. P., Lieut., U. S. N. R.

Brooks, John, Ensign, U. S. N. R.,
2020 100 Ave., Oakland, Calif.

Brown, William W., Commander, U. S. N.,
Bureau of Ships, Navy Dept., Mail, 416 Baltimore Ave., Washington 16, D. C.
Burr, James K., Lieut., U. S. N.
Byrd, Austin James, Jr., Lieut., U. S. N. R.
Cato, George Alfred, Ensign, U. S. N. R.
Chapman, John W., Ensign, U. S. N.
Coffin, Robert Cleveland, Jr., Ensign, U. S. N. R.
Compton, George P., Lieut., U. S. N.,
808 Hoover St., National City, Calif.
Coombs, Robert E., Captain, U. S. C. G. R.,
4416 49th St., N. W., Washington, D. C.
Curtin, J. F., Captain, U. S. N. R.,
26 Brokaw Lane, Great Neck, N. Y.
De Joia, Carmen Eric, Ensign, U. S. N. R.,
1099 Park Ave., Meadville, Pa.
Des Jardins, Paul R., Lieut., U. S. N. R.,
Board of Inspection & Survey, Navy Dept., Washington, D. C.
Dillon, Frederick P., Lieut., U. S. N. R.,
Aviation Safety Board, Naval Air Training Bases, Pensacola, Fla.
DiPilla, Edward, Ensign, U. S. N. R.
Dondero, Raymond S., Lieut., U. S. N. R.
Farnham, Donald Ross, Lieut. Commander, U. S. N. R.,
2332 Moraga St., San Francisco, Calif.
Farrin, James M., Jr., Commander, U. S. N.
Flanagan, Jack S., Ensign, U. S. N.
Forbush, Lothrop W., Ensign, U. S. N. R.
Fox, Robert P., Ensign, U. S. N. R.
Fulton S. DeWitt, Commander, U. S. N. R.,
48 S. Aberdeen St., Arlington, Va.
Gardner, Glenn, Lieut. Commander, U. S. N.
Gillette, Edward S., Ensign, U. S. N. R.
Glomb, George O., Lieut., U. S. N. R.,
Asst. to Eng. Officer, U. S. C. G., Cleveland, Ohio, Mail 13027 Lorain Ave., Cleveland, Ohio
Godlewski, Chester, Machinist, U. S. N. R.,
Turbine Erector, General Electric Co., Mail 1003 Pleasant St., Schenectady, N. Y.

Gunshanan, Robert W., Ensign, U. S. N. R.
Hall, Fred L., Lieut., U. S. N. R.
Hayes, Vernon R., Lieut. Commander, U. S. N.,
44 Park Ave., Williston Park, N. Y.
Heard, Walter W., Ensign, U. S. N. R.,
921 Prospect St., Shreveport, La.
Hewitt, Warren H., Lieut., U. S. N. R.
Hirsh, Edward F., Ensign, U. S. N.
Hoffman, Laurence N., Ensign, U. S. N.,
3607 N. 6th St., Fort Smith, Ark.
Jalbert, Llewellyn E., Ensign, U. S. N. R.,
P. O. Box 1053, Lewiston, Maine
Janett, Leslie G., Lieut., U. S. N. R.
Jones, Pete A. W., Machinist, U. S. N.
Katz, Bernard, Lieut., U. S. N. R.
Kendall, James G., Lieut., U. S. N.
Luer, Walter J., Lieut., U. S. N. R.
Lukas, Peter Paul, Ensign, U. S. N. R.
MacInnes, James, Lieut., U. S. N. R.
McDonald, William J., Lieut., U. S. N. R.,
care Downtown Athletic Club, 19 West St., New York 4. N. Y.
McGowan, Thomas J., Lieut., U. S. N.,
7445 N. Sheridan Road, Chicago, Ill.
McKinney, W. H., Lieut. Commander, U. S. N. R.
McKnight, Olin S., Ensign, U. S. N. R.,
4303 N. Pershing Drive, Arlington, Va.
Martens, Theodore James, Lieut. Commander, U. S. N.
Meanes, Glenn R., Ensign, U. S. N. R.,
803 South Normandie Ave., Los Angeles 5, Calif.
Meyer, Henry A., Lieut. Commander, U. S. N. R.
Mounger, Temple B., Lieut., U. S. N.,
24523 Eshelman Ave., Lomita, Calif.
Mullen, John F., Lieut., U. S. N. R.
Neeb, Lewis H., Lieut., U. S. N. R.
Neilund, William H., Lieut., U. S. N. R.
Neubert, Charles V., Chf. Carp. U. S. N.,
Bldg. 21, So. Boston Dry Dock, Boston 29, Mass.

Newman, Charles W., Jr., Lieut., U. S. N. R.,
care Asst. Ind. Mgr., U. S. N., Exchange Building, Seattle, Wash.
Pancher, R. I., Machinist, U. S. N.
Pascincco, John J., Lieut., U. S. N. R.
442 Quincy St., Dorchester, Mass.
Pearson, Eugene W., Lieut., U. S. N. R.,
464 44th St., Oakland, Calif.
Powers, George M., Jr., Commander, U. S. N., Inspector, Recruiting & Induction, New Court House & P. O. Bldg., Post Office Square, Boston 9, Mass.
Purinton, David Franklin, Ensign, U. S. N.
Ragland, R., Lieut., U. S. N.
Reeves, L. R., Machinist, U. S. N., care B. C. Reeves, 814 Booth St., Houston 9, Tex.
Rodgers, Donald R., Ensign, U. S. C. G.
Roemer, Rudolph H., Lieut., U. S. N. R.,
134 Davison Ave., Lynbrook, L. I., N. Y.
Rose, T. Foster, Lieut., U. S. N. R.
Rowe, Donald Marmaduke, Ensign, U. S. N. R., Room 115, Sage Hall, Class 16-45, N. T. S. Cornell University, Ithaca, N. Y.
Russell, Donald Burton, Lieut., U. S. N. R.
44 Jameson Road, Newton, Mass.
Sales, Edgar T., Lieut., U. S. N. R.
Schroder, John E. A., Lieut., U. S. N. R.,
1540 North Mason Ave., Chicago, 51, Ill.
Sinyei, Louis, Lieut., U. S. N.,
298 East Sewalls Point Road, Norfolk, Va.
Smith, Meyer F. W., Jr., Lieut., U. S. N. R.
Soebbing, Thomas J., Ensign, U. S. N. R.,
54 N. Main St., Ipswich, Mass.
Spaulding, Ronald Henry, Jr., Ensign, U. S. N. R.,
316-19 168th St., Flushington, N. Y.
Strobel, Mitchell P., Lieut., U. S. N.
Tennett, John P., Lieut., U. S. N. R.
Van Leeuwen, N. J., Lieut., U. S. N. R., Office I. N. M., Milwaukee Dist., Mail 2511 North Stowell Ave., Milwaukee 11, Wis.
Vinson, Cecil R., Machinist, U. S. N.
Yockers, Donald C., Ensign, U. S. N.

CIVIL.

Carr, John D., Naval Architect, U. S. Navy Dry Docks, Terminal Island, San Pedro, Calif., Mail 846 Pacific Ave., Long Beach, Calif.

Cawood, Ernest, Marine Engineer, Piping Section, Navy Yard, Philadelphia, Pa., Mail 43 N. Childs St., Woodbury, N. J.

Frink, James C., Marine Application Engineer on Naval and Marine Machinery, Westinghouse Elec. & Mfg. Co., 40 Wall St., New York, N. Y.

Gleitz, Jerome Darius, Vice President, Marquette Metals Products Co., Cleveland, Ohio, Mail 25901 Lake Shore Boulevard, Euclid, Ohio.

Johnson, James O., Chief Product Engineer,
Aircraft Marine Products, Ins. 1523 N. 4th St., Harrisburg, Pa.

Koenig, Benjamin, Chief Metallurgist, Chief of Ordnance War Dept., Room 4c-400, Pentagon Building, Washington, D. C.

Mellon, J. J., President,
Clark Controller Co., 1146 E. 152d Ave., Cleveland 10, Ohio

Miller, Ralph A.,
Apt. 343, 1601 Argonne Place, N. W., Washington 9, D. C.

Sjostrom, Carl H., Asst., Naval Architect, Sun Shipbuilding & Dry Dock Co., Chester, Pa., Mail, 4924 Hazel Ave., Philadelphia 43, Pa.

Smith, W. Tilford, Asst. Supt., Machinery, Newport News Shipbuilding & Dry Dock Co., Newport News, Va.

Wood, Robert F., Member, Washington Technical Services, 810 18th St., N. W., Washington 6, D. C.

ASSOCIATE.

Beach, David Duncan, Jr., Asso. N. A., C. D. Roach, Fort Lauderdale, Fla., Mail 719 N. East Fourth St., Fort Lauderdale, Fla.

Brewer, Frank M., Marine Engineer, Bureau of Ships, Navy Dept., Mail 1762 Preston Road, Alexandria, Va.

Emmert, Leonard R., Application Engineer, Westinghouse Elec. & Mfg. Co., 1101 Commonwealth Bldg., 1625 K St., N. W., Washington, D. C.

Pent, Robert E., Manufacturer of Wood Tops, P. O. Box 698 New Braunfels, Texas

Schwenk, Norris, H. President,
Busch-Sulzer Bros. Diesel Engine Co., 300 S. Second St., St. Louis 18, Mo.

Sedgwick, Harry K., Captain T. C., U. S. A.,
Apt. 11, 319 Howell Ave., Cincinnati 20, Ohio

Swint, William, Leading Man Machinist, Navy Yard, Philadelphia, Pa., Mail 6801 Burtleton Pike, Philadelphia 24, Pa.

Whiting, C. Randolph, Major, Signal Corps, U. S. A., 8702 31st Ave., Elmhurst, N. Y.